



AGRICULTURAL RESEARCH INSTITUTE

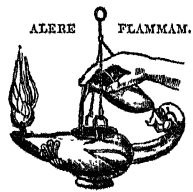
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REPORT
OF THE
THIRTY-NINTH MEETING
OF THE
BRITISH ASSOCIATION
FOR THE
ADVANCEMENT OF SCIENCE;
HELD AT
EXETER IN AUGUST 1869.

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Illustrative of the Report of the Committee on Electrical Standards.

ERRATA IN REPORT FOR 1868.

- Reports, p. 399, lines 20-22, *for* maximum still occurs. . . November, *read* maxima have occurred on the 6th-7th of December, but of which symptoms (Greg's A₁₆) can be distinguished as early as the 23rd of November.
- p. 399, lines 23, 24, *for* on... on . date. *read* in... in... month.
- p. 399, line 27, *for* May *read* March or April
- p. 400, last line, *for* Chapelas. *read* Chapelas-Coulvier-Gravier.
- p. 403, line 4 from bottom, *for* Max. 1848-52. *read* Max. Dec. 6-7, 1798 (?), 1838, 1847, 1848-52. Perhaps connected with Biela's comet.
- p. 407, line 11 from bottom, *for* 12th of December, including, perhaps, *read* beginning of December, including
- p. 407, last line, *add*, and Father Secchi that of "uranoliths" to designate aërolites.

ERRATA IN THE PRESENT VOLUME.

- Reports, p. 274, 20th line from bottom, *for* northward *read* southward
- | | | | | |
|---|------|---|---|--|
| " | 19th | " | " | <i>for</i> fifty-four <i>read</i> fifty |
| " | 17th | " | " | <i>for</i> south <i>read</i> north |
| " | 16th | " | " | <i>for</i> northerly <i>read</i> southerly |

OBJECTS AND RULES

OF

THE ASSOCIATION.

OBJECTS.

THE ASSOCIATION contemplates no interference with the ground occupied by other institutions. Its objects are,—To give a stronger impulse and a more systematic direction to scientific inquiry,—to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another and with foreign philosophers,—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.

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The Association shall meet annually, for one week, or longer. The place of each Meeting shall be appointed by the General Committee at the previous Meeting; and the Arrangements for it shall be entrusted to the Officers of the Association.

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The General Committee shall sit during the week of the Meeting, or longer, to transact the business of the Association. It shall consist of the following persons:—

1. Presidents and Officers for the present and preceding years, with authors of Reports in the Transactions of the Association.

2. Members who have communicated any Paper to a Philosophical Society, which has been printed in its Transactions, and which relates to such subjects as are taken into consideration at the Sectional Meetings of the Association.

3. Office-bearers for the time being, or Delegates, altogether not exceeding three in number, from any Philosophical Society publishing Transactions.

4. Office-bearers for the time being, or Delegates, not exceeding three, from Philosophical Institutions established in the place of Meeting, or in any place where the Association has formerly met.

5. Foreigners and other individuals whose assistance is desired, and who are specially nominated in writing for the Meeting of the year by the President and General Secretaries.

6. The Presidents, Vice-Presidents, and Secretaries of the Sections are *ex-officio* members of the General Committee for the time being.

SECTIONAL COMMITTEES.¹

The General Committee shall appoint, at each Meeting, Committees, consisting severally of the Members most conversant with the several branches of Science, to advise together for the advancement thereof.

The Committees shall report what subjects of investigation they would particularly recommend to be prosecuted during the ensuing year, and brought under consideration at the next Meeting.

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Local Committees shall be formed by the Officers of the Association to assist in making arrangements for the Meetings.

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In the intervals of the Meetings, the affairs of the Association shall be managed by a Council appointed by the General Committee. The Council may also assemble for the despatch of business during the week of the Meeting.

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The Author of any paper or communication shall be at liberty to reserve his right of property therein.

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The Accounts of the Association shall be audited annually, by Auditors appointed by the Meeting.

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BATH, September 14, 1864.

{ The Right Hon. the Earl of Cork and Orrery, Lord Lieutenant of Somer-
setshire
The Most Noble the Marquis of Bath
The Right Hon. Earl Nelson
The Right Hon. Lord Portman
The Very Reverend the Dean of Hereford
The Venerable the Archdeacon of Bath
W. TUG, Esq., M.P., F.R.S., F.G.S., F.S.A.
A. E. Way, Esq., M.P.
Francis H. Dickinson, Esq.
W. Sanders, Esq., F.R.S., F.G.S. }

C. Moore, Esq., F.G.S.
C. E. Davis, Esq.
The Rev. H. H. Wanwood, M.A.

JOHN PHILLIPS, Esq., M.A., LL.D., F.R.S., F.G.S.,
Professor of Geology in the University of Oxford
BIRMINGHAM, September 6, 1865.

{ The Right Hon. the Earl of Lichfield, Lord-Lieutenant of Staffordshire.
The Right Hon. the Earl of Dudley, Lord-Lieutenant of Warwickshire.
The Right Hon. Lord Leigh, Lord-Lieutenant of Worcestershire.
The Right Hon. Lord Lyttelton, Lord-Lieutenant of Worcestershire.
The Right Hon. Lord Wrottesley, M.A., D.C.L., F.R.S., F.R.A.S.
The Right Reverend the Lord Bishop of Worcester.
The Right Hon. C. B. Adderley, M.P.
William Scholefield, Esq., M.P. ... F. Osler, Esq., F.R.S.
J. T. Chance, Esq. The Rev. Charles Evans, M.A. ... }

William Matthews, Esq., jun., F.G.S.
John Henry Chamberlain, Esq.
The Rev. G. D. Bayly, M.A.

LOCAL SECRETARIES.

His Grace the Duke of Devonshire, Lord-Lieutenant of Dorsetshire
His Grace the Duke of Rutland, Lord-Lieutenant of Leicestershire
The Right Hon. Lord Belper, Lord-Lieutenant of Nottinghamshire.
The Right Hon. J. E. Denison, M. P.
C. Webb, Esq., High Sheriff of Nottinghamshire
J. C. Hooper, Esq., High Sheriff of Nottingham
Joseph Hocking, M. D., F.R.S., F.L.S.
John Russell Hinds Esq., F.R.S., F.R.A.S.
T. Cluse, Esq.

The Right Hon. the Earl of Airlie, K.T.
 The Right Hon. the Lord Kinnaird, K.T.
 Sir John Ogilvy, Bart., M.P.
 Sir David Baxter, Bart., M.P.
 Sir Roderick I. Murellston, Bart., K.C.B., LL.D., F.R.S., F.G.S., &c.
 Sir David Brewster, D.C.L., F.R.S., Principal of the University of Edinburgh.
 James D. Forbes, LL.D., F.R.S., Principal of the United College of St. Salvador and St. Leonard's, University of St. Andrews.

The Right Hon. the Earl of Leicester, Lord-Lieutenant of Norfolk.
Sir John Ponter, Bart., F.R.S.
Sir John Peter Boultan, Bart., F.R.S.
The Rev. Adam Sedwick, M.A., LL.D., F.R.S., F.G.S., &c., Woodwardian Professor of Geology in the University of Cambridge.
Sir John Lubbock, Bart., F.R.S., F.L.S., F.G.S.
Sir John Couch Adams, Esq., M.A., D.C.L., F.R.S., F.R.A.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge.
Thomas Brightwell, Esq.

The Right Hon. The Earl of Devon.....
The Right Hon. Sir Stafford H. Northcote, C.B., Bart., M.P., &c.....
Sir John Bowring, *LL.D.*, F.R.S.....
William B. Carpenter, M.D., F.R.S., F.L.S.....
Robert Vere Fox, Esq., F.R.S.....
W. H. Fox Talbot, Esq., M.A., *LL.D.*, F.R.S., F.L.S.....

The Right Hon. The Earl of Derby, LL.D., F.R.S.
The Hon. George Herbert Eserton, Bart., M.P.
The Right Hon. Wm. Pitt Rivers, LL.D., M.P.
Sir R. S. Graves, Esq., M.P., LL.D., D.C.L., F.R.S.
Sir Joseph Whitworth, Bart., LL.D., D.C.L., F.R.S.
James P. Joule, LL.D., D.C.L., F.R.S.
Joseph Mayer, Esq., F.S.A., F.R.G.S.

Dr. Robertson.
Edward J. Lowe, Esq., F.R.A.S., F.L.S.
The Rev. J. F. McCallan, M.A.

J. Henderson, Esq., jun.
John Austin Lake Glog, Esq.
Patrick Anderson, Esq.

Dr. Donald Dalrymple.
Rev. Joseph Crompton, M.A.
Rev. Canon Hinds Howell.

Henry S. Ellis, Esq., F.R.A.S.
John C. Bowring, Esq.
The Rev. R. Kirvan.

Rev. W. Banister.
Rev. Henry H. Higgins, M.A.
Rev. Dr. A. Hume, F.S.A.

Presidents and Secretaries of the Sections of the Association.

Date and Place.	Presidents.	Secretaries.
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MATHEMATICAL AND PHYSICAL SCIENCES.

COMMITTEE OF SCIENCES, I.—MATHEMATICS AND GENERAL PHYSICS.

1832. Oxford	[Davies Gilbert, D.C.L., F.R.S....]	Rev. H. Coddington.
1833. Cambridge	Sir D. Brewster, F.R.S.....	Prof. Forbes.
1834. Edinburgh	Rev. W. Whewell, F.R.S.....	Prof. Forbes, Prof. Lloyd.

SECTION A.—MATHEMATICS AND PHYSICS.

1835. Dublin	Rev. Dr. Robinson.....	Prof. Sir W. R. Hamilton, Prof. Wheatstone.
1836. Bristol	Rev. William Whewell, F.R.S....	Prof. Forbes, W. S. Harris, F. W. Jerrard.
1837. Liverpool ...	Sir D. Brewster, F.R.S.....	W. S. Harris, Rev. Prof. Powell, Prof. Stevelly.
1838. Newcastle...	Sir J. F. W. Herschel, Bart., F.R.S.	Rev. Prof. Chevallier, Major Sabine, Prof. Stevelly.
1839. Birmingham	Rev. Prof. Whewell, F.R.S.	J. D. Chance, W. Snow Harris, Prof. Stevelly.
1840. Glasgow ...	Prof. Forbes, F.R.S.	Rev. Dr. Forbes, Prof. Stevelly, Arch. Smith.
1841. Plymouth...	Rev. Prof. Lloyd, F.R.S.	Prof. Stevelly.
1842. Manchester	Very Rev. G. Peacock, D.D., F.R.S.	Prof. M'Culloch, Prof. Stevelly, Rev. W. Scoresby.
1843. Cork	Prof M'Culloch, M.R.I.A.	J. Nott, Prof. Stevelly.
1844. York	The Earl of Rosse, F.R.S.....	Rev. Wm. Hey, Prof. Stevelly.
1845. Cambridge..	The Very Rev. the Dean of Ely	Rev. H. Goodwin, Prof. Stevelly, G. G. Stokes.
1846. Southampton	Sir John F. W. Herschel, Bart., F.R.S.	John Drew, Dr. Stevelly, G. G. Stokes.
1847. Oxford	Rev. Prof. Powell, M.A., F.R.S.	Rev. H. Price, Prof. Stevelly, G. G. Stokes.
1848. Swansea	Lord Wrottesley, F.R.S.	Dr. Stevelly, G. G. Stokes.
1849. Birmingham	William Hopkins, F.R.S.	Prof. Stevelly, G. G. Stokes, W. Ridout Wills.
1850. Edinburgh ..	Prof. J. D. Forbes, F.R.S., Sec. R.S.E.	W. J. Macquorn Rankine, Prof. Smyth, Prof. Stevelly, Prof. G. G. Stokes.
1851. Ipswich.....	Rev. W. Whewell, D.D., F.R.S., &c.	S. Jackson, W. J. Macquorn Rankine, Prof. Stevelly, Prof. G. G. Stokes.
1852. Belfast	Prof. W. Thomson, M.A., F.R.S. L. & E.	Prof. Dixon, W. J. Macquorn Rankine, Prof. Stevelly, J. Tyndall.
1853. Hull	The Dean of Ely, F.R.S.	B. Blaydes Haworth, J. D. Sollitt, Prof. Stevelly, J. Welsh.
1854. Liverpool...	Prof. G. G. Stokes, M.A., Sec. R.S.	J. Hartnup, H. G. Puckle, Prof. Stevelly, J. Tyndall, J. Welsh.
1855. Glasgow ...	Rev. Prof. Kelland, M.A., F.R.S. L. & E.	Rev. Dr. Forbes, Prof. D. Gray, Prof. Tyndall.
1856. Cheltenham	Rev. R. Walker, M.A., F.R.S. ...	C. Brooke, Rev. T. A. Southwood, Prof. Stevelly, Rev. J. C. Turnbull.
1857. Dublin	Rev. T. R. Robinson, D.D., F.R.S., M.R.I.A.	Prof. Curtis, Prof. Hennessy, P. A. Ninnis, W. J. Macquorn Rankine, Prof. Stevelly.

Date and Place.	Presidents.	Secretaries.
1858. Leeds	Rev. W. Whewell, D.D., V.P.R.S.	Rev. S. Earnshaw, J. P. Hennessy, Prof. Stevelly, H. J. S. Smith, Prof. Tyndall.
1859. Aberdeen ...	The Earl of Rosse, M.A., K.P., F.R.S.	J. P. Hennessy, Prof. Maxwell, H. J. S. Smith, Prof. Stevelly.
1860. Oxford	Rev. B. Price, M.A., F.R.S.....	Rev. G. C. Bell, Rev. T. Rennison, Prof. Stevelly.
1861. Manchester ..	G. B. Airy, M.A., D.C.L., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1862. Cambridge ..	Prof. G. G. Stokes, M.A., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1863. Newcastle...	Prof. W. J. Ma Rankine, C.E., F.R.S.	Rev. N. Ferrers, Prof. Fuller, F. Jenkin, Prof. Stevelly, Rev. C. T. Whitley.
1864. Bath	Prof. Cayley, M.A., F.R.S., F.R.A.S.	Prof. Fuller, F. Jenkin, Rev. G. Buckle, Prof. Stevelly.
1865. Birmingham ..	W. Spottiswoode, M.A., F.R.S., F.R.A.S.	Rev. T. N. Hutchinson, F. Jenkin, G. S. Mathews, Prof. H. J. S. Smith, J. M. Wilson.
1866. Nottingham ..	Prof. Wheatstone, D.C.L., F.R.S.	Fleeming Jenkin, Prof. H. J. S. Smith, Rev. S. N. Swann.
1867. Dundee.....	Prof. Sir W. Thomson, D.C.L., F.R.S.	Rev. G. Buckle, Prof. G. C. Foster, Prof. Fuller, Prof. Swan.
1868. Norwich ...	Prof. J. Tyndall, LL.D., F.R.S.	Prof. G. C. Foster, Rev. R. Harley, R. B. Hayward.
1869. Exeter	Prof. J. J. Sylvester, LL.D., F.R.S.	Prof. G. C. Foster, R. B. Hayward, W. K. Clifford.

CHEMICAL SCIENCE.

COMMITTEE OF SCIENCES, II.—CHEMISTRY, MINERALOGY.

1832. Oxford	John Dalton, D.C.L., F.R.S.....	James F. W. Johnston.
1833. Cambridge...	John Dalton, D.C.L., F.R.S.....	Prof. Miller.
1834. Edinburgh...	Dr. Hope.....	Mr. Johnston, Dr. Christison.

SECTION B.—CHEMISTRY AND MINERALOGY.

1835. Dublin	Dr. T. Thomson, F.R.S.	Dr. Apjohn, Prof. Johnston.
1836. Bristol	Rev. Prof. Cumming.....	Dr. Apjohn, Dr. C. Henry, W. Herapath.
1837. Liverpool...	Michael Faraday, F.R.S.	Prof. Johnston, Prof. Miller, Dr. Reynolds.
1838. Newcastle...	Rev. William Whewell, F.R.S....	Prof. Miller, R. L. Pattinson, Thomas Richardson.
1839. Birmingham	Prof. T. Graham, F.R.S.	Golding Bird, M.D., Dr. J. B. Melson.
1840. Glasgow ...	Dr. Thomas Thomson, F.R.S. ...	Dr. R. D. Thomson, Dr. T. Clark, Dr. L. Playfair.
1841. Plymouth...	Dr. Daubeny, F.R.S.	J. Prideaux, Robert Hunt, W. M. Tweedy.
1842. Manchester ..	John Dalton, D.C.L., F.R.S.....	Dr. L. Playfair, R. Hunt, J. Graham.
1843. Cork	Prof. Apjohn, M.R.I.A.	R. Hunt, Dr. Sweeney.
1844. York	Prof. T. Graham, F.R.S.	Dr. R. Playfair, E. Solly, T. H. Barker.
1845. Cambridge...	Rev. Prof. Cumming.....	R. Hunt, J. P. Joule, Prof. Miller, E. Solly.
1846. Southampton	Michael Faraday, D.C.L., F.R.S.	Dr. Miller, R. Hunt, W. Randall.
1847. Oxford	Rev. W. V. Harcourt, M.A., F.R.S.	B. C. Brodie, R. Hunt, Prof. Solly.

Date and Place.	Presidents.	Secretaries.
1848. Swansea ...	Richard Phillips, F.R.S.	T. H. Henry, R. Hunt, T. Williams.
1849. Birmingham	John Percy, M.D., F.R.S.	R. Hunt, G. Shaw.
1850. Edinburgh	Dr. Christison, V.P.R.S.E.	Dr. Anderson, R. Hunt, Dr. Wilson.
1851. Ipswich ...	Prof. Thomas Graham, F.R.S. ...	T. J. Pearsall, W. S. Ward.
1852. Belfast	Thomas Andrews, M.D., F.R.S. ...	Dr. Gladstone, Prof. Hodges, Prof. Ronalds.
1853. Hull	Prof. J. F. W. Johnston, M.A., F.R.S.	H. S. Blundell, Prof. R. Hunt, T. J. Pearsall.
1854. Liverpool ...	Prof. W. A. Miller, M.D., F.R.S. ...	Dr. Edwards, Dr. Gladstone, Dr. Price.
1855. Glasgow ...	Dr. Lyon Playfair, C.B., F.R.S. ...	Prof. Frankland, Dr. H. E. Roscoe.
1856. Cheltenham	Prof. B. C. Brodie, F.R.S.	J. Horsley, P. J. Worsley, Prof. Voelcker.
1857. Dublin	Prof. Apjohn, M.D., F.R.S., M.R.I.A.	Dr. Davy, Dr. Gladstone, Prof. Sullivan.
1858. Leeds	Sir J. F. W. Herschel, Bart., D.C.L.	Dr. Gladstone, W. Odling, R. Reynolds.
1859. Aberdeen ...	Dr. Lyon Playfair, C.B., F.R.S. ...	J. S. Brazier, Dr. Gladstone, G. D. Liveing, Dr. Odling.
1860. Oxford	Prof. B. C. Brodie, F.R.S.	A. Vernon Harcourt, G. D. Liveing, A. B. Northcote.
1861. Manchester	Prof. W. A. Miller, M.D., F.R.S. ...	A. Vernon Harcourt, G. D. Liveing.
1862. Cambridge	Prof. W. A. Miller, M.D., F.R.S. ...	H. W. Elphinstone, W. Odling, Prof. Roscoe.
1863. Newcastle ...	Dr. Alex. W. Williamson, F.R.S. ...	Prof. Liveing, H. L. Pattinson, J. C. Stevenson.
1864. Bath	W. Odling, M.B., F.R.S., F.C.S. ...	A. V. Harcourt, Prof. Liveing, R. Biggs.
1865. Birmingham	Prof. W. A. Miller, M.D., V.P.R.S. ...	A. V. Harcourt, H. Adkins, Prof. Wanklyn, A. Winkler Wills.
1866. Nottingham	H. Bence Jones, M.D., F.R.S. ...	J. H. Atherton, Prof. Liveing, W. J. Russell, J. White.
1867. Dundee ...	Prof. T. Anderson, M.D., F.R.S.E. ...	A. Crum Brown, Prof. G. D. Liveing, W. J. Russell.
1868. Norwich ...	Prof. E. Frankland, F.R.S., F.C.S. ...	Dr. A. Crum Brown, Dr. W. J. Russell, F. Sutton.
1869. Exeter	Dr. H. Debus, F.R.S., F.C.S. ...	Prof. A. Crum Brown, M.D., Dr. W. J. Russell, Dr. Atkinson.

GEOLOGICAL (AND, UNTIL 1851, GEOGRAPHICAL) SCIENCE.

COMMITTEE OF SCIENCES, III.—GEOLOGY AND GEOGRAPHY.

1832. Oxford	R. I. Murchison, F.R.S.	John Taylor.
1833. Cambridge	G. B. Greenough, F.R.S.	W. Lonsdale, John Phillips.
1834. Edinburgh	Prof. Jameson	Prof. Phillips, T. Jameson Torrie, Rev. J. Yates.

SECTION C.—GEOLOGY AND GEOGRAPHY.

1835. Dublin	R. J. Griffith	Captain Portlock, T. J. Torrie.
1836. Bristol	Rev. Dr. Buckland, F.R.S.— <i>Geography</i> . R. I. Murchison, F.R.S.	William Sanders, S. Stutchbury, T. J. Torrie.
1837. Liverpool ...	Rev. Prof. Sedgwick, F.R.S.— <i>Geography</i> . G. B. Greenough, F.R.S.	Captain Portlock, R. Hunter.— <i>Geography</i> . Captain H. M. Denham, R.N.
1838. Newcastle ...	C. Lyell, F.R.S., V.P.G.S.— <i>Geography</i> . Lord Prudhope.	W. C. Trevelyan, Capt. Portlock.— <i>Geography</i> . Capt. Washington.
1839. Birmingham	Rev. Dr. Buckland, F.R.S.— <i>Geography</i> . G. B. Greenough, F.R.S.	George Lloyd, M.D., H. E. Strickland, Charles Darwin.

Date and Place.	Presidents.	Secretaries.
1840. Glasgow ...	Charles Lyell, F.R.S.— <i>Geography</i> . G. B. Greenough, F.R.S.	W. J. Hamilton, D. Milne, Hugh Murray, H. E. Strickland, John Scouler, M.D.
1841. Plymouth ...	H. T. De la Beche, F.R.S.	W. J. Hamilton, Edward Moore, M.D., R. Hutton.
1842. Manchester	R. I. Murchison, F.R.S.	E. W. Binney, R. Hutton, Dr. R. Lloyd, H. E. Strickland,
1843. Cork	Richard E. Griffith, F.R.S., M.R.I.A.	Francis M. Jennings, H. E. Strickland.
1844. York	Henry Warburton, M.P., Pres. Geol. Soc.	Prof. Ansted, E. H. Bunbury.
1845. Cambridge]	Rev. Prof. Sedgwick, M.A., F.R.S.	Rev. J. C. Cumming, A. C. Ramsay, Rev. W. Thorp.
1846. Southampton	Leonard Horner, F.R.S.— <i>Geography</i> . G. B. Greenough, F.R.S.	Robert A. Austen, J. H. Norton, M.D., Prof. Oldham.— <i>Geography</i> . Dr. C. T. Beke.]
1847. Oxford	Very Rev. Dr. Buckland, F.R.S.	Prof. Ansted, Prof. Oldham, A. C. Ramsay, J. Ruskin.
1848. Swansea ...	Sir H. T. De la Beche, C.B., F.R.S.	Starling Benson, Prof. Oldham, Prof. Ramsay.
1849. Birmingham	Sir Charles Lyell, F.R.S., F.G.S.	J. Beete Jukes, Prof. Oldham, Prof. A. C. Ramsay.
1850. Edinburgh *	Sir Roderick I. Murchison, F.R.S.	A. Keith Johnston, Hugh Miller, Professor Nicol.

SECTION C (*continued*).—GEOLOGY.

1851. Ipswich ...	William Hopkins, M.A., F.R.S.	C. J. F. Bunbury, G. W. Ormerod, Scarcles Wood.
1852. Belfast	Lieut.-Col. Portlock, R.E., F.R.S.	James Bryce, James MacAdam, Prof. M'Coy, Prof. Nicol.
1853. Hull	Prof. Sedgwick, F.R.S.	Prof. Harkness, William Lawton.
1854. Liverpool ..	Prof. Edward Forbes, F.R.S. ...	John Cunningham, Prof. Harkness, G. W. Ormerod, J. W. Woodall.
1855. Glasgow ...	Sir R. I. Murchison, F.R.S.	James Bryce, Prof. Harkness, Prof. Nicol.
1856. Cheltenham	Prof. A. C. Ramsay, F.R.S.	Rev. P. B. Brodie, Rev. R. Hepworth, Edward Hull, J. Scougall, T. Wright.
1857. Dublin	The Lord Talbot de Malahide ...	Prof. Harkness, Gilbert Sanders, Robert H. Scott.
1858. Leeds	William Hopkins, M.A., LL.D., F.R.S.	Prof. Nicol, H. C. Sorby, E. W. Shaw.
1859. Aberdeen...	Sir Charles Lyell, LL.D., D.C.L., F.R.S.	Prof. Harkness, Rev. J. Longmuir, H. C. Sorby.
1860. Oxford	Rev. Prof. Sedgwick, LL.D., F.R.S., F.G.S.	Prof. Harkness, Edward Hull, Capt. Woodall.
1861. Manchester	Sir R. I. Murchison, D.C.L., LL.D., F.R.S., &c.	Prof. Harkness, Edward Hull, T. Rupert Jones, G. W. Ormerod.
1862. Cambridge	J. Beete Jukes, M.A., F.R.S.	Lucas Barrett, Prof. T. Rupert Jones, H. C. Sorby.
1863. Newcastle...	Prof. Warrington, W. Smyth, F.R.S., F.G.S.	E. F. Boyd, John Daglish, H. C. Sorby, Thomas Sopwith.
1864. Bath	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	W. B. Dawkins, J. Johnston, H. C. Sorby, W. Pengelly.

* At the Meeting of the General Committee held in Edinburgh, it was agreed "That the subject of Geography be separated from Geology and combined with Ethnology, to constitute a separate Section, under the title of the "Geographical and Ethnological Section," for Presidents and Secretaries of which see page xxxi.

Date and Place.	Presidents.	Secretaries.
1865. Birmingham	Sir R. I. Murchison, Bart., K.C.B.	Rev. P. B. Brodie, J. Jones, Rev. E. Myers, H. C. Sorby. W. Pengelly.
1866. Nottingham	Prof. A. C. Ramsay, LL.D., F.R.S.	R. Etheridge. W. Pengelly, T. Wilson, G. H. Wright.
1867. Dundee.....	Archibald Geikie, F.R.S., F.G.S.	Edward Hull, W. Pengelly, Henry Woodward.
1868. Norwich ...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	Rev. O. Fisher, Rev. J. Gunn, W. Pengelly, Rev. H. H. Winwood.
1869. Exeter	Prof. R. Harkness, F.R.S., F.G.S.	W. Pengelly, W. Boyd Dawkins, Rev. H. H. Winwood.

BIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, IV.—ZOOLOGY, BOTANY, PHYSIOLOGY, ANATOMY.

1832. Oxford	Rev. P. B. Duncan, F.G.S.	Rev. Prof. J. S. Henslow.
1833. Cambridge*	Rev. W. L. P. Garmons, F.L.S....	C. C. Babington, D. Don.
1834. Edinburgh	Prof. Graham.....	W. Yarrell, Prof. Burnett.

SECTION D.—ZOOLOGY AND BOTANY.

1835. Dublin	Dr. Allman.....	J. Curtis, Dr. Litton.
1836. Bristol	Rev. Prof. Henslow	J. Curtis, Prof. Don, Dr. Riley, S. Rootsey.
1837. Liverpool..	W. S. MacLeay	C. C. Babington, Rev. L. Jenyns, W. Swainson.
1838. Newcastle...	Sir W. Jardine, Bart.....	J. E. Gray, Prof. Jones, R. Owen, Dr. Richardson.
1839. Birmingham	Prof. Owen, F.R.S.	E. Forbes, W. Ick, R. Patterson.
1840. Glasgow ...	Sir W. J. Hooker, LL.D	Prof. W. Couper, E. Forbes, R. Patterson.
1841. Plymouth...	John Richardson, M.D., F.R.S..	J. Couch, Dr. Lankester, R. Patterson.
1842. Manchester	Hon. and Very Rev. W. Herbert, LL.D., F.L.S.	Dr. Lankester, R. Patterson, J. A. Turner.
1843. Cork	William Thompson, F.L.S.	G. J. Allman, Dr. Lankester, R. Patterson.
1844. York.....	Very Rev. The Dean of Manchester.	Prof. Allman, H. Goodsir, Dr. King, Dr. Lankester.
1845. Cambridge	Rev. Prof. Henslow, F.L.S.	Dr. Lankester, T. V. Wollaston.
1846. Southampton	Sir J. Richardson, M.D., F.R.S.	Dr. Lankester, T. V. Wollaston, H. Wooldridge.
1847. Oxford.....	H. E. Strickland, M.A., F.R.S....	Dr. Lankester, Dr. Melville, T. V. Wollaston.

SECTION D (*continued*).—ZOOLOGY AND BOTANY, INCLUDING PHYSIOLOGY.

[For the Presidents and Secretaries of the Anatomical and Physiological Subsections and the temporary Section E of Anatomy and Medicine, see pp. xxx, xxxi.]

1848. Swansea ...	L. W. Dillwyn, F.R.S.	Dr. R. Wilbraham Falconer, A. Henfrey, Dr. Lankester.
1849. Birmingham	William Spence, F.R.S.....	Dr. Lankester, Dr. Russell.
1850. Edinburgh.	Prof. Goodsir, F.R.S. L. & E. ...	Prof. J. H. Bennett, M.D., Dr. Lankester, Dr. Douglas MacLagan.
1851. Ipswich.....	Rev. Prof. Henslow, M.A., F.R.S.	Prof. Allman, F. W. Johnston, Dr. E. Lankester.
1852. Belfast	W. Ogilby	Dr. Dickie. George C. Hyndman, Dr. Edwin Lankester.

* At this Meeting Physiology and Anatomy were made a separate Committee, for Presidents and Secretaries of which see p. xxx.

Date and Place.	Presidents.	Secretaries.
1853. Hull	C. C. Babington, M.A., F.R.S....	Robert Harrison, Dr. E. Lankester.
1854. Liverpool ...	Prof. Balfour, M.D., F.R.S.....	Isaac Byerley, Dr. E. Lankester.
1855. Glasgow ...	Rev. Dr. Fleming, F.R.S.E. ...	William Keddle, Dr. Lankester.
1856. Cheltenham.	Thomas Bell, F.R.S., Pres.L.S....	Dr. J. Abercrombie, Prof. Buckman, Dr. Lankester.
1857. Dublin	Prof. W. H. Harvey, M.D., F.R.S.	Prof. J. R. Kinahan, Dr. E. Lankester, Robert Patterson, Dr. W. E. Steele.
1858. Leeds.....	C. C. Babington, M.A., F.R.S....	Henry Denny, Dr. Hicaton, Dr. E. Lankester, Dr. E. Percival Wright.
1859. Aberdeen ...	Sir W. Jardine, Bart., F.R.S.E.	Prof. Dickie, M.D., Dr. E. Lankester, Dr. Ogilvy.
1860. Oxford	Rev. Prof. Henslow, F.L.S.	W. S. Church, Dr. E. Lankester, P. L. Slater, Dr. E. Percival Wright.
1861. Manchester..	Prof. C. C. Babington, F.R.S. ...	Dr. T. Alcock, Dr. E. Lankester, Dr. P. L. Slater, Dr. E. P. Wright.
1862. Cambridge...	Prof. Huxley, F.R.S.	Alfred Newton, Dr. E. P. Wright.
1863. Newcastle ...	Prof. Balfour, M.D., F.R.S.	Dr. E. Charlton, A. Newton, Rev. H. B. Tristram, Dr. E. P. Wright.
1864. Bath	Dr. John E. Gray, F.R.S.	H. B. Brady, C. E. Broom, H. T. Stainton, Dr. E. P. Wright.
1865. Birmingham	T. Thomson, M.D., F.R.S.	Dr. J. Anthony, Rev. C. Clarke, Rev. H. B. Tristram, Dr. E. P. Wright.

SECTION D (*continued*).—BIOLOGY*.

1866. Nottingham.	Prof. Huxley, LL.D., F.R.S.— <i>Physiological Dep.</i> Prof. Humphry, M.D., F.R.S.— <i>Anthropological Dep.</i> Alfred R. Wallace, F.R.G.S.	Dr. J. Beddard, W. Felkin, Rev. H. B. Tristram, W. Turner, E. B. Tylor, Dr. E. P. Wright.
1867. Dundee	Prof. Sharpey, M.D., Sec. R.S.— <i>Dep. of Zool. and Bot.</i> George Busk, M.D., F.R.S.	C. Spence Bate, Dr. S. Cobbold, Dr. M. Foster, H. T. Stainton, Rev. H. B. Tristram, Prof. W. Turner.
1868. Norwich ...	Rev. M. J. Berkeley, F.L.S.— <i>Dep. of Physiology.</i> W. H. Flower, F.R.S.	Dr. T. S. Cobbold, G. W. Firth, Dr. M. Foster, Prof. Tawson, H. T. Stainton, Rev. Dr. H. B. Tristram, Dr. E. P. Wright.
1869. Exeter	George Busk, F.R.S., F.L.S., <i>Dep.</i> <i>of Bot. and Zool.</i> C. Spence Bate, F.R.S., <i>Dep. of Ethno.</i> E. B. Tylor.	Dr. S. Cobbold, Prof. Michael Foster, M.D., E. Ray Lankester, Professor Lawson, H. T. Stainton, Rev. H. B. Tristram.

ANATOMICAL AND PHYSIOLOGICAL SCIENCES.

COMMITTEES OF SCIENCES, V.—ANATOMY AND PHYSIOLOGY.

1833. Cambridge..	Dr. Haviland	Dr. Bond, Mr. Paget.
1834. Edinburgh...	Dr. Abercrombie	Dr. Roget, Dr. William Thomson.

SECTION E. (UNTIL 1847).—ANATOMY AND MEDICINE.

1835. Dublin	Dr. Pritchard	Dr. Harrison, Dr. Hart.
1836. Bristol	Dr. Roget, F.R.S.	Dr. Symonds.
1837. Liverpool ...	Prof. W. Clark, M.D.	Dr. J. Carson, jun., James Long, Dr. J. R. W. Vose.
1838. Newcastle ...	T. E. Headlam, M.D.	T. M. Greenhow, Dr. J. R. W. Vose.
1839. Birmingham	John Yelloly, M.D., F.R.S.	Dr. G. O. Rees, F. Ryland.

* At the Meeting of the General Committee at Birmingham, it was resolved:—"That the title of Section D be changed to Biology;" and "That for the word 'Subsection,' in the rules for conducting the business of the Sections, the word 'Department' be substituted."

Date and Place.	Presidents.	Secretaries.
1840. Glasgow ...	James Watson, M.D.....	Dr. J. Brown, Prof. Couper, Prof. Reid.
1841. Plymouth...	P. M. Roget, M.D., Sec.R.S. ...	Dr. J. Butter, J. Fuge, Dr. R. S. Sargent.
1842. Manchester.	Edward Holme, M.D., F.L.S. ...	Dr. Chaytor, Dr. Sargent.
1843. Cork	Sir James Pitcairn, M.D.	Dr. John Popham, Dr. R. S. Sargent.
1844. York	J. C. Pritchard, M.D.	I. Erichsen, Dr. R. S. Sargent.

SECTION E.—PHYSIOLOGY.

1845. Cambridge	Prof. J. Haviland, M.D.	Dr. R. S. Sargent, Dr. Webster.
1846. Southampton	Prof. Owen, M.D., F.R.S.....	C. P. Keele, Dr. Laycock, Dr. Sargent.
1847. Oxford*	Prof Ogle, M.D., F.R.S.	Dr. Thomas, K. Chambers, W. P. Ormerod.

PHYSIOLOGICAL SUBSECTIONS OF SECTION D.

1850. Edinburgh	Prof. Bennett, M.D., F.R.S.E.	
1855. Glasgow ...	Prof. Allen Thomson, F.R.S. ...	Prof. J. H. Corbett, Dr. J. Struthers.
1857. Dublin	Prof. R. Harrison, M.D.	Dr. R. D. Lyons, Prof. Redfern.
1858. Leeds	Sir Benjamin Brodie, Bart. F.R.S.	C. G. Wheelhouse.
1859. Aberdeen ...	Prof. Sharpey, M.D., Sec.R.S. ...	Prof. Bennett, Prof. Redfern.
1860. Oxford	Prof. G. Rolleston, M.D., F.L.S.	Dr. R. McDonnell, Dr. Edward Smith.
1861. Manchester.	Dr. John Davy, F.R.S.L. & E....	Dr. W. Roberts, Dr. Edward Smith.
1862. Cambridge	C. E. Paget, M.D.	G. F. Helm, Dr. Edward Smith.
1863. Newcastle...	Prof. Rolleston, M.D., F.R.S. ...	Dr. D. Embleton, Dr. W. Turner.
1864. Bath	Dr. Edward Smith, LL.D., F.R.S.	J. S. Bartrum, Dr. W. Turner.
1865. Birmingham.†	Prof. Acland, M.D., LL.D., F.R.S.	Dr. A. Fleming, Dr. P. Heslop, Oliver Penbleton, Dr. W. Turner.

GEOGRAPHICAL AND ETHNOLOGICAL SCIENCES.

[For Presidents and Secretaries for Geography previous to 1851, see Section C, p. xxvii.]

ETHNOLOGICAL SUBSECTIONS OF SECTION D.

1846. Southampton	Dr. Pritchard.....	Dr. King.
1847. Oxford	Prof. H. H. Wilson, M.A.	Prof. Buckley.
1848. Swansea ...		G. Grant Francis.
1849. Birmingham		Dr. R. G. Latham.
1850. Glasgow ...	Vice-Admiral Sir A. Malcolm ...	Daniel Wilson.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

1851. Ipswich ...	Sir R. I. Murchison, F.R.S., Pres.	R. Cull, Rev. J. W. Donaldson, Dr. R. G. S. Norton Shaw.
1852. Belfast	Col. Chesney, R.A., D.O.L., F.R.S.	R. Cull, R. MacAdam, Dr. Norton Shaw.
1853. Hull	R. G. Latham, M.D., F.R.S. ...	R. Cull, Rev. H. W. Kemp, Dr. Norton Shaw.
1854. Liverpool...	Sir R. I. Murchison, D.C.L., F.R.S.	Richard Cull, Rev. H. Higgins, Dr. Ihne, Dr. Norton Shaw.
1855. Glasgow ...	Sir J. Richardson, M.D., F.R.S.	Dr. W. G. Blackie, R. Cull, Dr. Norton Shaw.
1856. Cheltenham	Col. Sir H. C. Rawlinson, K.C.B.	R. Cull, F. D. Hartland, W. H. Rumsey, Dr. Norton Shaw.

* By direction of the General Committee at Oxford, Sections D and E were incorporated under the name of "Section D—Zoology and Botany, including Physiology" (see p. xxix). The Section being then vacant was assigned in 1851 to Geography.

† *Vide* note on preceding page.

Date and Place.	Presidents.	Secretaries.
1857. Dublin	Rev. Dr. J. Henthawn Todd, Pres. R.I.A.	R. Cull, S. Ferguson, Dr. R. R. Madden, Dr. Norton Shaw.
1858. Leeds	Sir R. I. Murchison, G.C.St.S., F.R.S.	R. Cull, Francis Galton, P. O'Callaghan, Dr. Norton Shaw, Thomas Wright.
1859. Aberdeen ...	Rear-Admiral Sir James Clerk Ross, D.C.L., F.R.S.	Richard Cull, Professor Goddes, Dr. Norton Shaw.
1860. Oxford	Sir R. I. Murchison, D.C.L., F.R.S.	Capt. Burrows, Dr. J. Hunt, Dr. C. Lempriere, Dr. Norton Shaw.
1861. Manchester.	John Crawford, F.R.S.	Dr. J. Hunt, J. Kingsley, Dr. Norton Shaw, W. Spottiswoode.
1862. Cambridge	Francis Galton, F.R.S.	J. W. Clarke, Rev. J. Glover, Dr. Hunt, Dr. Norton Shaw, T. Wright.
1863. Newcastle...	Sir R. I. Murchison, K.C.B., F.R.S.	C. Carter Blake, Hume Greenfield, C. R. Markham, R. S. Watson.
1864. Bath.....	Sir R. I. Murchison, K.C.B., F.R.S.	H. W. Bates, C. R. Markham, Capt. R. M. Murchison, T. Wright.
1865. Birmingham	Major-General Sir R. Rawlinson, M.P., K.C.B., F.R.S.	H. W. Bates, S. Evans, G. Jabet, C. R. Markham, Thomas Wright.
1866. Nottingham	Sir Charles Nicholson, Bart., LL.D.	H. W. Bates, Rev. E. T. Cusins, R. H. Major, Clements R. Markham, D. W. Nash, T. Wright.
1867. Dundee.....	Sir Samuel Baker, F.R.G.S.	H. W. Bates, Cyril Graham, C. R. Markham, S. J. Mackie, R. Sturrock.
1868. Norwich ...	Capt. G. H. Richards, R.N., F.R.S.	T. Baines, H. W. Bates, C. R. Markham, T. Wright.

SECTION E (*continued*).—GEOGRAPHY.

1869. Exeter	Sir Bartle Frere, K.C.B., LL.D., F.R.G.S.	H. W. Bates, Clements R. Markham, J. H. Thomas.
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STATISTICAL SCIENCE.

COMMITTEES OF SCIENCES, VI.—STATISTICS.

1833. Cambridge	Prof. Babbage, F.R.S.	J. E. Drinkwater.
1834. Edinburgh	Sir Charles Lemon, Bart.	Dr. Cleland, C. Hope Maclean.

SECTION F.—STATISTICS.

1835. Dublin	Charles Babbage, F.R.S.	W. Greg, Prof. Longfield.
1836. Bristol	Sir Charles Lemon, Bart., F.R.S.	Rev. J. E. Bromby, C. B. Fripp, James Heywood.
1837. Liverpool...	Rt. Hon. Lord Sandon	W. R. Greg, W. Langton, Dr. W. C. Tayler.
1838. Newcastle...	Colonel Sykes, F.R.S.	W. Cargill, J. Heywood, W. R. Wood.
1839. Birmingham	Henry Hallam, F.R.S.	F. Clarke, R. W. Rawson, Dr. W. C. Tayler.
1840. Glasgow ...	Rt. Hon. Lord Sandon, F.R.S., M.P.	C. R. Baird, Prof. Ramsay, R. W. Rawson.
1841. Plymouth...	Lieut.-Col. Sykes, F.R.S.	Rev. Dr. Byrth, Rev. R. Luney, R. W. Rawson.
1842. Manchester.	G. W. Wood, M.P., F.L.S.	Rev. R. Luney, G. W. Ormerod, Dr. W. C. Tayler.
1843. Cork	Sir C. Lemon, Bart., M.P.	Dr. D. Bullen, Dr. W. Cooke Tayler.
1844. York	Lieut.-Col. Sykes, F.R.S., F.L.S.	J. Fletcher, J. Heywood, Dr. Laycock.
1845. Cambridge	Rt. Hon. The Earl Fitzwilliam...	J. Fletcher, W. Cooke Tayler, LL.D.
1846. Southampton	G. R. Porter, F.R.S.	J. Fletcher, F. G. P. Neison, Dr. W. C. Tayler, Rev. T. L. Shapcott.
1847. Oxford	Travers Twiss, D.C.L., F.R.S.	Rev. W. H. Cox, J. J. Danson, F. G. P. Neison.

Date and Place.	Presidents.	Secretaries.
1848. Swansea ...	J. H. Vivian, M.P., F.R.S.	J. Fletcher, Capt. R. Shortrede.
1849. Birmingham	Rt. Hon. Lord Lyttelton	Dr. Finch, Prof. Hancock, F. G. P. Neison.
1850. Edinburgh ..	Very Rev. Dr. John Lee, V.P.R.S.E.	Prof. Hancock, J. Fletcher, Dr. J. Stark.
1851. Ipswich	Sir John P. Bouleau, Bart.	J. Fletcher, Prof. Hancock.
1852. Belfast	His Grace the Archbishop of Dublin.	Prof. Hancock, Prof. Ingram, James MacAdam, Jun.
1853. Hull	James Heywood, M.P., F.R.S.	Edward Cheshire, William Newmarch.
1854. Liverpool ...	Thomas Tooke, F.R.S.	E. Cheshire, J. T. Danson, Dr. W. H. Duncan, W. Newmarch.
1855. Glasgow	R. Monckton Milnes, M.P.	J. A. Campbell, E. Cheshire, W. Newmarch, Prof. R. H. Walsh.

SECTION F (*continued*).—ECONOMIC SCIENCE AND STATISTICS.

1856. Cheltenham	Rt. Hon. Lord Stanley, M.P. ...	Rev. C. H. Bromby, E. Cheshire, Dr. W. N. Hancock Newmarch, W. M. Tartt.
1857. Dublin	His Grace the Archbishop of Dublin, M.R.I.A.	Prof. Cairns, Dr. H. D. Hutton, W. Newmarch.
1858. Leeds	Edward Baines	T. B. Baines, Prof. Cairns, S. Brown, Capt. Fishbourne, Dr. J. Strang.
1859. Aberdeen ...	Col. Sykes, M.P., F.R.S.	Prof. Cairns, Edmund Macrory, A. M. Smith, Dr. John Strang.
1860. Oxford	Nassau W. Senior, M.A.	Edmund Macrory, W. Newmarch, Rev. Prof. J. E. T. Rogers.
1861. Manchester	William Newmarch, F.R.S.	David Chadwick, Prof. R. C. Christie, E. Macrory, Rev. Prof. J. E. T. Rogers.
1862. Cambridge ..	Edwin Chadwick, C.B.	H. D. Macleod, Edmund Macrory.
1863. Newcastle ...	William Tite, M.P., F.R.S.	T. Doubleday, Edmund Macrory, Frederick Purdy, James Potts.
1864. Bath	William Farr, M.D., D.O.L., F.R.S.	E. Macrory, E. T. Payne, F. Purdy.
1865. Birmingham	Rt. Hon. Lord Stanley, LL.D., M.P.	G. J. D. Goodman, G. J. Johnston, E. Macrory.
1866. Nottingham	Prof. J. E. T. Rogers	R. Birkin, Jun., Prof. Leone Levi, E. Macrory.
1867. Dundee	M. E. Grant Duff, M.P.	Prof. Leone Levi, E. Macrory, A. J. Warden.
1868. Norwich ...	Samuel Brown, Pres. Instit. Actuaries.	Rev. W. C. Davie, Prof. Leone Levi.
1869. Exeter	Rt. Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.	Edmund Macrory, Frederick Purdy, Charles T. D. Acland.

MECHANICAL SCIENCE.

SECTION G.—MECHANICAL SCIENCE.

1836. Bristol	Davies Gilbert, D.O.L., F.R.S.	T. G. Bunt, G. T. Clark, W. West.
1837. Liverpool ...	Rev. Dr. Robinson	Charles Vignoles, Thomas Webster.
1838. Newcastle ...	Charles Babbage, F.R.S.	R. Hawthorn, C. Vignoles, T. Webster.
1839. Birmingham	Prof. Willis, F.R.S., and Robert Stephenson.	W. Carpmael, William Hawkes, Thomas Webster.
1840. Glasgow ...	Sir John Robinson	J. Scott Russell, J. Thomson, J. Tod, C. Vignoles.
1841. Plymouth ...	John Taylor, F.R.S.	Henry Chatfield, Thomas Webster.
1842. Manchester	Rev. Prof. Willis, F.R.S.	J. F. Bateman, J. Scott Russell, J. Thomson, Charles Vignoles.

Date and Place.	Presidents.	Secretaries.
1843. Cork	Prof. J. Macneill, M.R.I.A.	James Thompson, Robert Mallet.
1844. York	John Taylor, F.R.S.	Charles Vignoles, Thomas Webster.
1845. Cambridge ..	George Rennie, F.R.S.	Rev. W. T. Kingsley.
1846. Southampton	Rev. Prof. Willis, M.A., F.R.S. .	William Betts, Jun., Charles Manby.
1847. Oxford	Rev. Prof. Walker, M.A., F.R.S. .	J. Glynn, R. A. Le Mesurier.
1848. Swansea	Rev. Prof. Walker, M.A., F.R.S. .	R. A. Le Mesurier, W. P. Struvé.
1849. Birmingham	Robert Stephenson, M.P., F.R.S. .	Charles Manby, W. P. Marshall.
1850. Edinburgh ..	Rev. Dr. Robinson	Dr. Lees, David Stephenson.
1851. Ipswich	William Cubitt, F.R.S.	John Head, Charles Manby.
1852. Belfast	John Walker, C.E., LL.D., F.R.S. .	John F. Bateman, C. B. Hancock, Charles Manby, James Thomson.
1853. Hull	William Fairbairn, C.E., F.R.S. .	James Oldham, J. Thompson, W. Sykes Ward.
1854. Liverpool ...	John Scott Russell, F.R.S.	John Grantham, J. Oldham, J. Thom- son.
1855. Glasgow ...	W. J. Macquorn Rankine, C.E., F.R.S.	L. Hill, Jun., William Ramsay, J. Thomson.
1856. Cheltenham	George Rennie, F.R.S.	C. Atherton, B. Jones, Jun., H. M. Jeffery.
1857. Dublin	The Right Hon. The Earl of Rosse, F.R.S.	Prof. Downing, W. T. Doyne, A. Tate, James Thomson, Henry Wright.
1858. Leeds	William Fairbairn, F.R.S.	J. C. Dennis, J. Dixon, H. Wright.
1859. Aberdeen ...	Rev. Prof. Willis, M.A., F.R.S. .	R. Abernethy, P. Le Neve Foster, H. Wright.
1860. Oxford	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, Rev. F. Harrison, Henry Wright.
1861. Manchester .	J. F. Bateman, C.E., F.R.S.	P. Le Neve Foster, John Robinson, H. Wright.
1862. Cambridge ..	William Fairbairn, LL.D., F.R.S. .	W. M. Fawcett, P. Le Neve Foster.
1863. Newcastle ...	Rev. Prof. Willis, M.A., F.R.S. .	P. Le Neve Foster, P. Westmacott, J. F. Spencer.
1864. Bath	J. Hawkshaw, F.R.S.	P. Le Neve Foster, Robert Pitt.
1865. Birmingham	Sir W. G. Armstrong, LL.D., F.R.S.	P. Le Neve Foster, Henry Lea, W. P. Marshall, Walter May.
1866. Nottingham	Thomas Hawksley, V.P.Inst. C.E., F.G.S.	P. Le Neve Foster, J. F. Iselin, M. A. Tarbottom.
1867. Dundee	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, John P. Smith, W. W. Urquhart.
1868. Norwich ...	G. P. Bidder, C.E., F.R.G.S. ...	P. Le Neve Foster, J. F. Iselin, C. Manby, W. Smith.
1869. Exeter	C. W. Siemens, F.R.S.	P. Le Neve Foster, H. Baucman.

List of Evening Lectures.

Date and Place.	Lecturer.	Subject of Discourse.
1842. Manchester ..	Charles Vignoles, F.R.S.	The Principles and Construction of Atmospheric Railways.
	Sir M. I. Brunel	The Thames Tunnel.
	Sir R. I. Murchison, Bart.	The Geology of Russia.
1843. Cork	Prof. Owen, M.D., F.R.S.	The Dinornis of New Zealand.
	Prof. Forbes, F.R.S.	The Distribution of Animal Life in the Aegean Sea.
	Dr. Robinson	The Earl of Rosse's Telescope.
1844. York	Charles Lyell, F.R.S.	Geology of North America.
	Dr. Falconer, F.R.S.	The Gigantic Tortoise of the Siwalik Hills in India.
1845. Cambridge ..	G. B. Airy, F.R.S., Astron. Royal	Progress of Terrestrial Magnetism.
	R. I. Murchison, F.R.S.	Geology of Russia.

Date and Place.	Lecturer.	Subject of Discourse.
1846. Southampton	Prof. Owen, M.D., F.R.S. Charles Lyell, F.R.S. W. R. Grove, F.R.S.	Fossil Mammalia of the British Isles. Valley and Delta of the Mississippi. Properties of the Explosive substance discovered by Dr. Schönbein; also some Researches of his own on the Decomposition of Water by Heat.
1847. Oxford	Rev. Prof. B. Powell, F.R.S. ... Prof. M. Faraday, F.R.S.	Shooting-stars. Magnetic and Diamagnetic Phenomena.
1848. Swansea ...	Hugh E. Strickland, F.G.S. ... John Percy, M.D., F.R.S.	The Dodo (<i>Didus ineptus</i>). Metallurgical operations of Swansea and its neighbourhood.
1849. Birmingham	W. Carpenter, M.D., F.R.S. ... Dr. Faraday, F.R.S. Rev. Prof. Willis, M.A., F.R.S.	Recent Microscopical Discoveries. Mr. Gassiot's Battery. Transit of different Weights with varying velocities on Railways.
1850. Edinburgh.	Prof. J. H. Bennett, M.D., F.R.S.E.	Passage of the Blood through the minute vessels of Animals in connexion with Nutrition.
1851. Ipswich	Dr. Mantell, F.R.S. Prof. R. Owen, M.D., F.R.S.	Extinct Birds of New Zealand. Distinction between Plants and Animals, and their changes of Form.
1852. Belfast	G. B. Airy, F.R.S., Astron. Roy. Prof. G. G. Stokes, D.C.L., F.R.S.	Total Solar Eclipse of July 28, 1851. Recent discoveries in the properties of Light.
1853. Hull	Colonel Portlock, R.E., F.R.S.	Recent discovery of Rock-salt at Carrickfergus, and geological and practical considerations connected with it.
1853. Hull	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	Some peculiar phenomena in the Geology and Physical Geography of Yorkshire.
1854. Liverpool ...	Robert Hunt, F.R.S. Prof. R. Owen, M.D., F.R.S. ... Col. E. Sabine, V.P.R.S.	The present state of Photography. Anthropomorphous Apes. Progress of researches in Terrestrial Magnetism.
1855. Glasgow	Dr. W. B. Carpenter, F.R.S. ... Lieut.-Col. H. Rawlinson	Characters of Species. Assyrian and Babylonian Antiquities and Ethnology.
1856. Cheltenham	Col. Sir H. Rawlinson	Recent discoveries in Assyria and Babylonia, with the results of Cuneiform research up to the present time.
1857. Dublin	W. R. Grove, F.R.S. Prof. Thomson, F.R.S. Rev. Dr. Livingstone, D.C.L. ...	Correlation of Physical Forces. The Atlantic Telegraph. Recent discoveries in Africa.
1858. Leeds	Prof. J. Phillips, LL.D., F.R.S. Prof. R. Owen, M.D., F.R.S. ...	The Ironstones of Yorkshire. The Fossil Mammalia of Australia.
1859. Aberdeen ...	Sir R. I. Murchison, D.C.L. Rev. Dr. Robinson, F.R.S.	Geology of the Northern Highlands. Electrical Discharges in highly rarefied Media.
1860. Oxford	Rev. Prof. Walker, F.R.S. Captain Sherard Osborn, R.N. .	Physical Constitution of the Sun. Arctic Discovery.
1861. Manchester .	Prof. W. A. Miller, M.A., F.R.S. G. B. Airy, F.R.S., Astron. Roy. .	Spectrum Analysis. The late Eclipse of the Sun.
1862. Cambridge .	Prof. Tyndall, LL.D., F.R.S. ... Prof. Odling, F.R.S.	The Forms and Action of Water. Organic Chemistry.
1863. Newcastle-on-Tyne .:	Prof. Williamson, F.R.S. James Glaisher, F.R.S.	The chemistry of the Galvanic Battery considered in relation to Dynamics. The Balloon Ascents made for the British Association.

Date and Place.	Lecturer.	Subject of Discourse.
1864. Bath	Prof. Roscoe, F.R.S.....	The Chemical Action of Light.
	Dr. Livingstone, F.R.S.	Recent Travels in Africa.
1865. Birmingham	J. Beete Jukes, F.R.S.	Probabilities as to the position and extent of the Coal-measures beneath the red rocks of the Midland Counties.
1866. Nottingham.	William Huggins, F.R.S.....	The results of Spectrum Analysis applied to Heavenly Bodies.
	Dr. J. D. Hooker, F.R.S.....	Insular Floras.
1867. Dundee.....	Archibald Geikie, F.R.S.....	The Geological origin of the present Scenery of Scotland.
	Alexander Herschel, F.R.A.S....	The present state of knowledge regarding Meteors and Meteorites.
1868. Norwich	J. Fergusson, F.R.S.	Archæology of the early Buddhist Monuments.
	Dr. W. Odling, F.R.S.	Reverse Chemical Actions.
1869. Exeter	Prof. J. Phillips, LL.D., F.R.S.	Vesuvius.
	J. Norman Lockyer, F.R.S.....	The Physical Constitution of the Stars and Nebulæ.

Lectures to the Operative Classes.

1867. Dundee.....	Prof. J. Tyndall, LL.D., F.R.S.	Matter and Force.
1868. Norwich	Prof. Huxley, LL.D., F.R.S. ...	A piece of Chalk.
1869. Exeter	Prof. Miller, M.D., F.R.S.	Experimental illustrations of the modes of detecting the Composition of the Sun and other Heavenly Bodies by the Spectrum.

OFFICERS AND COUNCIL, 1869-70.

TRUSTEES (PERMANENT).

Sir RODERICK I. MURCHISON, Bart., K.C.B., G.C.St.S., D.C.L., F.R.S.
 Lieut.-General Sir EDWARD SABINE, K.C.B., R.A., D.C.L., Pres. R.S.
 Sir PHILIP DE M. GREY EGERTON, Bart., M.P., F.R.S.

PRESIDENT.

GEORGE G. STOKES, M.A., D.C.L., Sec. R.S., Lucasian Professor of Mathematics in the University of Cambridge.

VICE-PRESIDENTS.

The Right Hon. The EARL OF DEVON.	WILLIAM B. CARPENTER, M.D., F.R.S., F.L.S.
The Right Hon. Sir STAFFORD H. NORTHCOTE, C.B., Bart., M.P., &c.	ROBERT WERE FOX, Esq., F.R.S.
Sir JOHN BOWRING, LL.D., F.R.S.	W. H. FOX TALBOT, M.A., LL.D., F.R.S., F.L.S.

PRESIDENT ELECT.

T. H. HUXLEY, LL.D., F.R.S., F.L.S., Pres. G.S., Professor of Natural History in the Royal School of Mines.

VICE-PRESIDENTS ELECT.

Right Hon. The EARL OF DERBY, LL.D., F.R.S.	Sir JOSEPH WHITWORTH, Bart., LL.D., D.C.L., F.R.S.
Sir PHILIP DE M. GREY EGERTON, Bart., M.P.	JAMES P. JOULE, Esq., LL.D., D.C.L., F.R.S.
The Right Hon. W. E. GLADSTONE, D.C.L., M.P.	JOSEPH MAYER, Esq., F.S.A., F.R.G.S.
S. R. GRAVES, Esq., M.P.	

LOCAL SECRETARIES FOR THE MEETING AT LIVERPOOL.

Rev. W. BANISTER.
 Rev. HENRY H. HIGGINS, M.A.
 Rev. A. HUME, D.C.L., F.S.A.

LOCAL TREASURER FOR THE MEETING AT LIVERPOOL.

H. DUCKWORTH, Esq., F.R.G.S.

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BUSK, GEORGE, Esq., F.R.S.	RAMSAY, Professor, F.R.S.
DE LA RUE, WARREN, Esq., F.R.S.	RANKINE, Professor W. J. M., F.R.S.
EVANS, JOHN, Esq., F.R.S.	RICHARDS, Captain, R.N., F.R.S.
GALTON, Capt. DOUGLAS, C.B., R.E., F.R.S.	SHARPEY, Dr., Sec. R.S.
GALTON, FRANCIS, Esq., F.R.S.	SMITH, Professor H. J. S., F.R.S.
GASSIOT, J. P., Esq., F.R.S.	STRANGE, Lieut.-Colonel A., F.R.S.
GODWIN-AUSTEN, R. A. C., Esq., F.R.S.	SYKES, Colonel, M.P., F.R.S.
HOUGHTON, Right Hon. Lord, D.C.L., F.R.S.	SYLVESTER, Prof. J. J., LL.D., F.R.S.
HUGGINS, WILLIAM, Esq., F.R.S.	TITE, Sir W., M.P., F.R.S.
LUBBOCK, Sir JOHN, Bart., F.R.S.	TYNDALL, Professor, F.R.S.
MILLER, Prof. W. A., M.D., F.R.S.	WHEATSTONE, Professor Sir C., F.R.S.
NEWMARCH, WILLIAM, Esq., F.R.S.	WILLIAMSON, Prof. A. W., F.R.S.
ODLING, WILLIAM, Esq., M.B., F.R.S.	

EX-OFFICIO MEMBERS OF THE COUNCIL.

The President and President Elect, the Vice-Presidents and Vice-Presidents Elect, the General and Assistant General Secretaries, the General Treasurer, the Trustees, and the Presidents of former years, viz. :—

Rev. Professor Sedgwick.	Lt.-General Sir E. Sabine, K.C.B.	Sir W. G. Armstrong, C.B., LL.D.
The Duke of Devonshire.	The Earl of Harrowby.	Sir Chas. Lyell, Bart., M.A., LL.D.
Rev. W. V. Harcourt.	The Duke of Argyll.	Professor Phillips, M.A., D.C.L.
Sir John F. W. Herschel, Bart.	The Rev. H. Lloyd, D.D.	William R. Grove, Esq., F.R.S.
Sir R. I. Murchison, Bart., K.C.B.	Richard Owen, M.D., D.C.L.	The Duke of Buccleuch, K.B.
The Rev. T. K. Robinson, D.D.	Sir W. Fairbairn, Bart., LL.D.	Dr. Joseph D. Hooker, F.R.S.
G. B. Airy, Esq., Astronomer Royal.	The Rev. Professor Willis, F.R.S.	

GENERAL SECRETARIES.

T. ARCHER HIRST, Esq., F.R.S., F.R.A.S., Professor of Mathematics in University College, London.
 Dr. THOMAS THOMSON, F.R.S., Kew Green, Kew.

ASSISTANT GENERAL SECRETARY.

GEORGE GRIFFITH, Esq., M.A., 1 Woodside, Harrow.

GENERAL TREASURER.

WILLIAM SPOTTISWOODE, Esq., M.A., F.R.S., F.R.G.S., 60 Grosvenor Place, London, S.W.

AUDITORS.

Professor W. Allen Miller, F.R.S. G. Busk, Esq., F.R.S. Professor G. C. Foster, F.R.S.

Table showing the Attendance and Receipts

Date of Meeting.	Where held.	Presidents.		
			Old Life Members.	New Life Members.
1831, Sept. 27 ...	York	The Earl Fitzwilliam, D.C.L. ...	...	...
1832, June 19 ...	Oxford	The Rev. W. Buckland, F.R.S. ...	...	...
1833, June 25 ...	Cambridge	The Rev. A. Sedgwick, F.R.S. ...	...	...
1834, Sept. 8 ...	Edinburgh	Sir T. M. Brisbane, D.C.L.	...	...
1835, Aug. 10 ...	Dublin	The Rev. Provost Lloyd, LL.D. ...	...	...
1836, Aug. 23 ...	Bristol	The Marquis of Lansdowne	...	...
1837, Sept. 11 ...	Liverpool	The Earl of Burlington, F.R.S. ...	...	...
1838, Aug. 10 ...	Newcastle-on-Tyne ..	The Duke of Northumberland ...	...	...
1839, Aug. 26 ...	Birmingham	The Rev. W. Vernon Harcourt. ...	...	...
1840, Sept. 17 ...	Glasgow	The Marquis of Breadalbane ...	...	...
1841, July 20 ...	Plymouth	The Rev. W. Whewell, F.R.S. ...	169	65
1842, June 23 ...	Manchester	The Lord Francis Egerton	303	169
1843, Aug. 17 ...	Cork	The Earl of Rosse, F.R.S.	109	28
1844, Sept. 26 ...	York	The Rev. G. Peacock, D.D.	226	150
1845, June 19 ...	Cambridge	Sir John F. W. Herschel, Bart. ...	313	36
1846, Sept. 10 ...	Southampton	Sir Roderick I. Murchison, Bart. ...	241	10
1847, June 23 ...	Oxford	Sir Robert H. Inglis, Bart.	314	18
1848, Aug. 9 ...	Swansea	The Marquis of Northampton ...	149	3
1849, Sept. 12 ...	Birmingham	The Rev. T. R. Robinson, D.D. ...	227	12
1850, July 21 ...	Edinburgh	Sir David Brewster, K.H.	235	9
1851, July 2 ...	Ipswich	G. B. Airy, Esq., Astron. Royal. ...	172	8
1852, Sept. 1 ...	Belfast	Lieut.-General Sabine, Pres. R.S. ...	164	10
1853, Sept. 3 ...	Hull	William Hopkins, Esq., F.R.S. ...	141	13
1854, Sept. 20 ...	Liverpool	The Earl of Harrowby, F.R.S. ...	238	23
1855, Sept. 12 ...	Glasgow	The Duke of Argyll, F.R.S.	194	33
1856, Aug. 6 ...	Cheltenham	Prof. C. G. J. Daubeny, M.D.	182	14
1857, Aug. 26 ...	Dublin	The Rev. Humphrey Lloyd, D.D. ...	236	15
1858, Sept. 22 ...	Leeds	Richard Owen, M.D., D.C.L. ...	222	42
1859, Sept. 14 ...	Aberdeen	H.R.H. The Prince Consort ..	184	27
1860, June 27 ...	Oxford	The Lord Wrottesley, M.A.	286	21
1861, Sept. 4 ...	Manchester	William Fairbairn, LL.D., F.R.S. ...	321	113
1862, Oct. 1 ...	Cambridge	The Rev. Prof. Willis, M.A. ...	239	15
1863, Aug. 26 ...	Newcastle-on-Tyne ..	Sir William G. Armstrong, C.B. ...	203	36
1864, Sept. 13 ...	Bath	Sir Charles Lyell, Bart., M.A.	287	40
1865, Sept. 6 ...	Birmingham	Prof. J. Phillips, M.A., LL.D.	292	44
1866, Aug. 23 ...	Nottingham	William R. Grove, Q.C., F.R.S. ...	207	31
1867, Sept. 4 ...	Dundee	The Duke of Buccleuch, K.C.B. ...	167	25
1868, Aug. 19 ...	Norwich	Dr. Joseph D. Hooker, F.R.S. ...	196	18
1869, Aug. 18 ...	Exeter	Prof. G. G. Stokes, D.C.L.	204	21
1870, Sept. 14 ...	Liverpool	Prof. T. H. Huxley, LL.D.		

at Annual Meetings of the Association.

Attended by						Amount received during the Meeting.	Sums paid on Account of Grants for Scientific Purposes.
Old Annual Members.	New Annual Members.	Associates.	Ladies.	Foreigners.	Total.		
...	...	...	...	...	353	£ s. d.	£ s. d.
...	...	...	...	...	...		
...	...	...	...	...	900	.....	.....
...	...	...	...	...	1298	.....	.....
...	...	...	...	...	...	.....	20 0 0
...	...	...	...	...	...	.....	167 0 0
...	...	...	...	...	1350	.....	434 14 0
...	...	...	...	...	1840	.....	918 14 6
...	...	...	1100*	...	2400	.....	956 12 2
...	...	...	...	34	1438	.....	1595 11 0
...	...	...	...	40	1353	.....	1546 16 4
46	317	...	60*	...	891	.....	1235 10 11
75	376	33†	331*	28	1315	.....	1449 17 8
71	185	...	160	...	...	.....	1565 10 2
45	190	9†	260	...	...	.....	981 12 8
94	22	407	172	35	1079	.....	830 9 9
65	39	270	196	36	857	.....	685 16 0
197	40	495	203	53	1260	.....	208 5 4
54	25	376	197	15	929	707 0 0	275 1 8
93	33	447	237	22	1071	963 0 0	159 19 6
128	42	510	273	44	1241	1085 0 0	345 18 0
61	47	244	141	37	710	620 0 0	391 9 7
63	60	510	292	9	1108	1085 0 0	304 6 7
56	57	367	236	6	876	903 0 0	205 0 0
121	121	765	524	10	1802	1882 0 0	330 19 7
142	101	1094	543	26	2133	2311 0 0	480 16 4
104	48	412	346	9	1115	1098 0 0	734 13 9
156	120	900	569	26	2022	2015 0 0	507 15 3
111	91	710	509	13	1698	1931 0 0	618 18 2
125	179	1206	821	22	2564	2782 0 0	684 11 1
177	59	636	463	47	1689	1604 0 0	1241 7 0
184	125	1589	791	15	3139	3944 0 0	1111 5 10
150	57	433	242	25	1161	1089 0 0	1293 16 6
154	209	1704	1004	25	3335	3640 0 0	1608 3 10
182	103	1119	1058	13	2802	2965 0 0	1289 15 8
215	149	766	508	23	1997	2227 0 0	1591 7 10
218	105	960	771	11	2303	2469 0 0	1750 13 4
193	118	1163	771	7	2444	2613 0 0	1739 4 0
226	117	720	682	†45	2004	2042 0 0	1940 0 0
229	107	678	600	17	1856	1931 0 0	.....

* Ladies were not admitted by purchased Tickets until 1843.

† Tickets for admission to Sections only.

‡ Including Ladies

THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE GENERAL TREASURER'S ACCOUNT from 20th August 1868 (commencement of NORWICH Meeting) to 18th August 1869 (EXETER).

RECEIPTS.

To Balance brought from last Account	177	1	7
Received for Life Compositions at Norwich Meeting and since	220	0	0
" Annual Subscriptions, ditto ditto	624	0	0
" Associates' Tickets, ditto ditto	720	0	0
" Ladies' Tickets, ditto ditto	682	0	0
" Dividends on Stock	249	3	2
" Sale of Publications—viz.			
Reports	49	15	8
Index, Catalogue of Stars, &c.	8	10	4
" Sale of Consols (£500 Stock)	58	6	0
" of Mr. Catton, being portion of Grant of £60 made at Dundee, for Researches on the Synthesis of Organic Acids, but not used (£12 less Commission on Cheque)	463	15	0
	11	19	8

Examined and found correct, November 16, 1869.

WM. ALLEN MILLER, M.D.,
GEO. BUSK,
G. C. FOSTER, } *Auditors.*



£3206 5 5

PAYMENTS.

By Expenses of Norwich Meeting, also Sundry Printing, Binding, Advertising, and Incidental Petty Expenses	346	4	;
" Printing, Engraving, and Binding Report of 37th Meeting (Dundee)	711	0	;
" Salaries (1 year)	350	0	;
" Grants made at Norwich Meeting, viz. —			

Maintaining Establishment of Kew Observatory...	£600	0	0
Lunar Committee	50	0	0
Metric Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	30	0	0
Thermal Conductivity of Iron &c.	30	0	0
Plant's Root Explorations	130	0	0
Steel Pen	30	0	0
Chemical Constitution of Cast Iron	80	0	0
Iron and Steel Manufacture	100	0	0
Methyl Series	30	0	0
Organic Remains in Limestone Rocks	10	0	0
Scottish Earthquakes	10	0	0
British Fossil Corals	50	0	0
English Lead-Beds	50	0	0
Total Flooding	25	0	0
Tidal Observations	100	0	0
Underground Temperature	30	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Organic Acids	12	0	0
Thermoelectricity	20	0	0
Chemical Constitution and Physiological Action Relations	15	0	0
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	10	0	0
Products of Digestion	10	0	0
1869.	1622	0	0

Aug. 18. Balance at London and Westminster Bank £170 13 9
" in hands of General Treasurer ... 6 7 3

W. SPOTTISWOODE,
August 18, 1869.

177 1 0
£3206 5 5

OFFICERS OF SECTIONAL COMMITTEES PRESENT AT THE EXETER MEETING.

SECTION A.—MATHEMATICS AND PHYSICS.

President.—Professor J. J. Sylvester, M.A., LL.D., F.R.S.

Vice-Presidents.—Professor J. C. Adams, M.A., D.C.L., F.R.S.; J. P. Gassiot, V.P.R.S.; William R. Grove, M.A., F.R.S.; Rev. Professor Bartholomew Price, M.A., F.R.S.; Rev. T. R. Robinson, D.D., F.R.S.; Professor Sir Charles Wheatstone, D.C.L., F.R.S.

Secretaries.—Professor G. C. Foster, B.A., F.R.S.; R. B. Hayward, M.A.; W. K. Clifford, B.A.

SECTION B.—CHEMISTRY AND MINERALOGY, INCLUDING THEIR APPLICATIONS TO AGRICULTURE AND THE ARTS.

President.—Dr. H. Debus, F.R.S., F.C.S.

Vice-Presidents.—Dr. Andrews; Dr. J. Hall Gladstone, F.R.S.; Professor W. A. Miller, M.D., F.R.S.; Dr. Voelcker, F.C.S.; Dr. Williamson, F.R.S. Pres.C.S.

Secretaries.—Professor A. Crum Brown, M.D., F.C.S.; Dr. W. J. Russell, F.C.S.; Dr. Atkinson, F.C.S.

SECTION C.—GEOLOGY.

President.—Professor R. Harkness, F.R.S., F.G.S.

Vice-Presidents.—R. A. C. Godwin-Austen, F.R.S., F.G.S.; Sir P. de M. Grey Egerton, Bart., F.R.S., F.G.S.; Professor Phillips, LL.D., P.R.S., F.G.S.; Professor Huxley, LL.D., F.R.S., P.G.S.; Edward Vivian, F.G.S.

Secretaries.—W. Pengelly, F.R.S., F.G.S.; W. Boyd Dawkins, M.A., F.R.S., F.G.S.; Rev. H. H. Winwood, M.A., F.G.S.

SECTION D.—BIOLOGY.

President.—George Busk, F.R.S., F.L.S., F.G.S.

Vice-Presidents.—Professor Balfour, F.R.S.; C. Spence Bate, F.R.S., F.L.S.; Dr. Hooker, F.R.S., F.L.S.; Sir John Lubbock, Bart., F.R.S.; Dr. W. Ransom; E. B. Tylor; A. R. Wallace, F.R.G.S.; Professor E. Perceval Wright, M.D., F.L.S.

Secretaries.—Dr. Spencer Cobbold, F.R.S.; Professor Michael Foster, M.D., F.R.S.; E. Ray Lankester; Professor Lawson; H. T. Stainton, F.R.S., F.L.S.; Rev. H. B. Tristram, M.A., LL.D., F.R.S.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

President.—Sir Bartle Frere, K.C.B., F.R.G.S., LL.D., G.C.S.I.

Vice-Presidents.—Sir G. Grey, K.C.B., F.R.G.S.; A. G. Findlay, F.R.G.S.; Major-General Sir A. Scott Waugh, R.E., F.R.S.; Captain Richards, R.N., F.R.S.; Vice-Admiral Sir E. Belcher, K.C.B., F.R.G.S.

Secretaries.—H. W. Bates, Assist. Sec. R.G.S.; Clements R. Markham, F.R.G.S.; J. H. Thomas, F.R.G.S.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

President.—The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.

Vice-Presidents.—T. D. Acland, M.A., D.C.L., M.P.; The Earl of Derby, F.R.S.; The Right Hon. Lord Houghton, D.C.L., F.R.S.; Sir W. Tite, M.P., F.R.S.; Dr. Wm. Farr, D.C.L., F.R.S.; Professor J. E. Thorold Rogers, M.A.

Secretaries.—Edmund Macrory, M.A.; Frederick Purdy, F.S.S.; Charles T. D. Acland, M.A.

SECTION G.—MECHANICAL SCIENCE.

President.—C. W. Siemens, C.E., F.R.S.

Vice-Presidents.—G. P. Bidder, C.E.; C. Vignoles, C.E., F.R.S., F.R.A.S.; Professor W. M. Rankine, LL.D., F.R.S.; Rev. Professor Willis, F.R.S.; C. H. Gregory, Pres.I.C.E.; Admiral Sir E. Belcher, K.C.B.; Captain Douglas Galton, C.E., R.E., F.R.S.; J. F. Bateman, F.R.S.; F. J. Bramwell; Sir Joseph Whitworth, Bart., LL.D., F.R.S.

Secretaries.—P. Le Neve Foster, M.A.; H. Bauerman, F.G.S.

Report of the Council of the British Association for the year 1868–69, presented to the General Committee at Exeter on Wednesday, August 18, 1869.

The Reports of the General Treasurer and of the Kew Committee for the past year have been received, and will be laid before the General Committee.

At the Meeting of the Association at Norwich, the General Committee referred two Resolutions to the Council for consideration and action, if it should be deemed desirable.

The first Resolution was :—

That the Council be instructed to prepare and cause to be presented to the Houses of Lords and Commons petitions on behalf of the Association, praying them without loss of time to pass such measures as will remedy the existing defects in Secondary Education in Schools, and that the Council be empowered to take such other steps as in their judgment may be best calculated to promote the object of these petitions.

The Council, after receiving the report of a Committee specially appointed by them to consider the question, resolved to act in accordance with this Resolution. They consequently prepared the following Petition, which was presented by the Right Hon. Lord Lyttelton to the House of Lords, by Sir W. Tite to the House of Commons.

The Humble Petition of the British Association for the Advancement
of Science

Sheweth,—That one of the ends for which the Association was established was to “obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.”

That some of the chief impediments to the progress of Science in the United Kingdom are to be found in the limited and defective state of Secondary Education, and in the condition of the Endowed Grammar Schools, which, having been founded in past times, represent for the most part the knowledge and wants of the past, rather than of the present.

That, notwithstanding the defects of the Endowed Grammar Schools, they are enabled, by their number, antiquity, and endowments, to maintain a prescriptive rank and influence, and seriously to impede the adoption of improved systems of education.

That the necessity for inquiry into the state of the Endowed Grammar Schools, and into the education given in schools generally, above the Elementary, has already been recognized in the appointment by Her Majesty of three Commissions to report on this Class of Schools in England and Scotland.

That in the year 1866 the Council of the Association appointed a Committee to consider the best means of promoting Scientific Education in Schools, and that this Committee drew up a Report on the subject, which is printed

in the "Report of the Schools-Inquiry Commission," presented to Her Majesty, and laid before your Honourable House.

That the recommendations of the Schools-Inquiry Commission, in regard to the introduction of the study of Natural Science into all Secondary Schools, are in general accordance with the views of the Association.

That, in the opinion of the Association, the study of Natural Science, whether as a means of disciplining the mind, or for providing knowledge useful for the purposes of life, is of essential importance to the youth of this country; and that it ought to form a part of education in all Secondary Schools.

That the Association consider the Secondary Education of the United Kingdom, both in regard to the quality and the range of the subjects of study, to be incommensurate with the needs of a well-organized state; they therefore request your Honourable House to enact such laws as shall make Natural Science an essential part of the course of education, and to put it on a footing of equality with the most favoured subjects of study.

The Second Resolution referred to the Council by the General Committee at Norwich was:—

That the Council of the British Association be requested to urge upon Government and through the British Government upon the Governments of Foreign Nations, the importance of fixing, by permanent bench-marks, certain points of level, and also of position in reference to secular changes (1st) in the elevation of the land as referred to the sea-level, and (2nd) in relation to changes of coast-line, and to the position of ice-masses.

That the Council of this Association be requested to ask the support and cooperation in this of the Council of the Royal Society; and that the following be a Committee to assist the Council and that of the Royal Society in the definition of the works proposed to be executed:—W. Sartorius von Waltershausen, Lieut.-Colonel Sir Henry James, R.E., F.R.S., Robert A. C. Godwin-Austen, F.R.S.

The Council appointed a Committee, consisting of Sir Henry James, Sir C. Wheatstone, Mr. Godwin-Austen, Professor Tyndall, Professor Ramsay, the President, General Secretaries, and Treasurer, to consider this resolution and to report thereon.

This Report being favourable, your Council applied to the Council of the Royal Society, who at once promised their support in any application to Government, but deemed it unnecessary to augment the Committee already elected by your Council for the purpose of defining the works proposed to be executed. This Committee has not yet concluded its labours.

The following foreign men of Science, who were present at the Norwich Meeting, have been elected Corresponding Members:—

Baron von Mädler, Dorpat.	Professor L. Radlkofer, Munich.
Padre Secchi, Director of the Observatory at Rome.	Professor Karl Koch.
Professor Aug. Morren, Doyen de la Faculté de Science, Marseilles.	M. D'Avesac, Mem. de l'Institut de France.
Professor Vogt, Geneva.	Dr. H. A. Weddell, Poitiers.
Professor Broca, Paris.	M. A. Heynsius, Leyden.

The Council are able to report that the Annual Volume was this year again issued in June; a still earlier publication being desirable, however, it is proposed to publish the next volume at Christmas: but in order to do so it will be necessary to defer until the following year the publication of

reports which are not ready for the press immediately after the close of this present Meeting of the Association.

The Council have been informed that Invitations for 1870 will be presented to the General Committee by Deputations from Liverpool, Edinburgh, Brighton, and Bradford.

Report of the Kew Committee of the British Association for the Advancement of Science for 1868-69.

The Committee of the Kew Observatory submit to the Council of the British Association the following statement of their proceedings during the past year :—

The nature and amount of assistance to be rendered by this Committee to the Meteorological Committee of the Royal Society have now been clearly defined, and the duties undertaken at Kew Observatory may, as in the last Report, for clearness' sake be again considered under the two following heads :—

- (A) The work done under the direction of the British Association.
- (B) That done at Kew as the Central Observatory of the Meteorological Committee.

This system of division will be adopted in this Report, and it has been thought desirable, for the information of the Association, in the financial statement hereto appended, to include the sums received from the Meteorological Committee as well as those received from the British Association. It will thus be clearly seen that the work done at Kew for the Meteorological Committee has been paid for from funds supplied by that Committee, and not in any way from money subscribed by the British Association.

(A) WORK DONE BY KEW OBSERVATORY UNDER THE DIRECTION OF THE
BRITISH ASSOCIATION.

1. *Magnetic work.*—The Self-recording Magnetographs ordered by the Mauritius Government for Mr. Meldrum, after having been verified at Kew, have been forwarded to their destination.

A Unifilar and Dip-circle for Mr. Meldrum have likewise been verified.

A Unifilar and Dip-circle have been repaired and verified for the Rev. M. Colombel, who has gone to Nankin, where he intends making magnetical observations.

M. Colombel as well as M. Berg, of the Wilna Observatory, have received magnetical instruction at Kew.

A Dip-circle is in the course of being verified for Lieut. Elagin, of the Russian Navy.

The usual monthly absolute determinations of the magnetic elements continue to be made by Mr. Whipple, Magnetic Assistant. During the last year it has been found necessary to replace the wooden pillars of the magnetic house with pillars of Portland stone, which had been previously ascertained to be non-magnetic. It has also been found necessary slightly to repair the Unifilar and Dip-circle hitherto used in these monthly determinations.

The Self-recording Magnetographs are in constant operation as heretofore, also under the charge of Mr. Whipple, and the photographic department connected with these instruments remains under the charge of Mr. Page.

The task of tabulating and reducing the magnetic curves produced at Kew

subsequent to January 1865 is in progress under the direction of Mr. Stewart. Considerable advance has been made in these reductions during the present year, and it is hoped that during the next session of the Royal Society a paper may be communicated to that body by Mr. Stewart, giving certain results of these reductions, as well as results of the absolute magnetic observations made every month.

Lieut. Elagin has communicated through Mr. Stewart to the Royal Society an account of observations made at the various European observatories, by means of a Dip-circle which had been lent to him from the Kew Observatory.

Mr. Stewart has likewise communicated to the Royal Society a short paper by Senhor Capello "On the reappearance of certain periods of Declination-disturbance during two, three, or several days;" also a joint paper by the Rev. W. Sidgreaves and himself, embodying the results of a preliminary comparison of the Kew and Stonyhurst declination-curves; also a paper embodying the magnetical results obtained by Lieut. Rokeby at the island of Ascension, reduced by Mr. Whipple, Magnetical Assistant at Kew. Finally, Mr. Stewart has communicated to the Royal Society a paper containing a preliminary discussion of the peaks and hollows of the Kew magnetic curves for the first two years during which the Magnetographs were in operation.

2. *Meteorological work.*—The meteorological work of the Observatory continues in the charge of Mr. Baker.

Since the Norwich Meeting, 157 Barometers have been verified, and 27 have been rejected; 1153 thermometers have been verified, and 24 have been rejected. Two Standard Thermometers have been constructed for the Standards' Commission*, one for Stonyhurst College, and nine for Professor Tait. 38 Hydrometers have likewise been verified.

The progressive nature of this department of the Kew work will be seen by the following statement of the numbers of Barometers and Thermometers verified during the last few years:—

	Barometers.	Thermometers.
1863-64	97	389
1864-65	88	420
1865-66	126	395
1866-67	89	608
1867-68	78	1139
1868-69	157	1153

The self-recording meteorological instruments now at work at Kew will be again mentioned in the second division of this Report. These are in the charge of Mr. Baker, the photography being superintended by Mr. Page.

A Self-recording Barograph verified at Kew for Messrs. R. & J. Beck has been disposed of by these opticians to Mr. Meldrum, of the Mauritius Observatory. A Barograph and Thermograph have been verified at Kew and dispatched to Mr. Ellery, at Melbourne, and a Barograph has recently been verified for Mr. Smalley, of Sydney.

At the request of Mr. G. J. Symons, the old Kew Thermometer frame has been lent to him for certain experiments, which are being carried on by him in conjunction with the Rev. C. H. Griffith, at Strathfield Turgis.

The attention of meteorologists is directed towards an instrument devised by Mr. Beckley, mechanical assistant at Kew, for the purpose of registering

* While this Report was being printed, an application was received from the Warden of the Standards, through Lieut.-Gen. Sir Edward Sabine, for an Air Thermometer.

the rainfall automatically. A description of this instrument will be submitted to the Association at Exeter.

Attention is likewise directed to a paper to be communicated by Mr. Balfour Stewart to the Association at the Exeter Meeting, entitled "Remarks on Meteorological Reductions, with especial reference to the Element of Vapour;" separate copies of which will be at the disposal of Members.

The following revised fees are charged for the verification of meteorological instruments at Kew:—

	<i>s.</i>	<i>d.</i>
Barometers (requiring index- and capacity-corrections) ..	10	0
Ditto (not requiring capacity-correction—inches measured) ..	5	0
Thermometers (ordinary).....	1	0
Boiling-point Thermometers	2	6
Hydrometers.....	1	0

3. *Photoheliograph*.—The Kew Heliograph, in charge of Mr. De La Rue, continues to be worked in a satisfactory manner. During the past year 274 negatives have been taken on 168 days: 40 pictures of the Pagoda in Kew Gardens, as a fixed terrestrial object at a known distance, have likewise been taken, with the object of determining, by measurements of these pictures, which are taken in different parts of the field of the telescope, both the optical distortion of the sun-pictures and the angular diameter of the Sun.

A paper communicated to the Royal Society by Messrs. Warren De La Rue, Stewart, and Loewy, entitled "Researches on Solar Physics.—Heliographical Positions and Areas of Sun-spots observed with the Kew Photoheliograph during the years 1862 and 1863," is the first of the series of reductions of the photographic solar records; it is in the course of publication in the 'Transactions' and will shortly be distributed.

It is hoped that, during next winter, a paper containing the heliographical positions and areas of the spots observed at Kew during the years 1864, 1865, and 1866 may be communicated to the Royal Society, as well as a paper representing, both numerically and graphically, the spotted area of the sun during three complete solar periods, the results being partly derived from Schwabe's and partly from Carrington's observations, in addition to those made with the Kew photoheliograph.

Another paper by the above authors, entitled "Account of some Recent Observations on Sun-spots made at the Kew Observatory," has likewise been ordered to be published in the 'Philosophical Transactions.'

M. Berg, of the Wilna Observatory, has during the past year received instruction at Kew in the method of taking Solar Photographs and in that of measuring the positions and areas of sun-spots, the Director of the Observatory with which he is connected being desirous of working along with Kew, and of following out the same methods of observation as well as the same researches.

The number of sun-spots recorded after the manner of Hofrath Schwabe, together with a Table exhibiting the monthly groups observed at Dossau and at Kew for the year 1868, have been communicated to the Astronomical Society, and published in their 'Monthly Notices.'

We regret to mention that Hofrath Schwabe, owing to his great age, has found it necessary to discontinue his observations; but the Committee have satisfaction in stating that arrangements have been made for continuing, at Kew, the grouping of sun-observations which has been carried on for some

time according to Hofrath Schwabe's plan, and for publishing the results annually.

A minute comparison of the records of Hofrath Schwabe with the simultaneous photographic records at Kew has revealed the great trustworthiness of his drawings, which are at present in the possession of Kew Observatory. The proposed communication already alluded to as representing the spotted area of the sun during three complete solar periods is thus rendered possible; and while it is imagined that by this means a valuable record of the past will be obtained, it is hoped that the interest now displayed in solar research will secure the uninterrupted continuance of such a record for the future.

4. *Miscellaneous work.*—The Superintendent has recently received a grant of £60 from the Government-Grant Committee of the Royal Society for the purpose of continuing certain experiments by Prof. Tait and himself on the rotation of a disk *in vacuo*; and means are in progress for obtaining a nearly perfect vacuum, Mr. Beckley, Mechanical Assistant at Kew, having devised an apparatus for this purpose.

An account of preliminary observations made with Kater's pendulum by the Superintendent, in conjunction with Mr. B. Loewy, has been communicated to the Royal Society.

The instrument devised by Mr. Broun for the purpose of estimating the magnetic dip by means of soft iron, constructed at the expense of the British Association, remains at present at the Observatory awaiting Mr. Broun's return to England.

The Observatory was honoured on June 25th by a visit from the eminent French chemist, M. Dumas, permanent Secretary of the Imperial Academy of Sciences, Paris, accompanied by M. Hervé-Mangon.

(B) WORK DONE AT KEW AS THE CENTRAL OBSERVATORY OF THE METEOROLOGICAL COMMITTEE.

The relation between the two Committees, the Kew and the Meteorological, has during the last year been definitely settled.

The Kew Committee have undertaken to maintain the self-recording instruments belonging to the Meteorological Committee in regular operation at Kew, to tabulate from the traces, and to forward the traces and tabulations once a month to the central office of the Meteorological Committee in London, where they will be finally reduced, under the supervision of the Director of that office. They have also sanctioned the employment of such assistance by Mr. Stewart as may be necessary to enable him to examine the records which arrive from the various outlying observatories of the Meteorological Committee in accordance with a plan which has been approved by that body. Once a week, therefore, documents from these various observatories arrive at Kew, and about the middle of each month the documents for all the observatories (including Kew) for the previous month, after having been well examined, are forwarded to the Meteorological Office with a few remarks, which are printed in the Minutes of the Meteorological Committee.

Besides these duties which they have undertaken, the Kew Committee are glad to render the Meteorological Committee any occasional assistance which it may be in their power to bestow.

1. *Work done at Kew as one of the Observatories of the Meteorological Committee.*—This consists in keeping in constant operation the Barograph, Thermograph, and Anemograph furnished by the Meteorological Committee. Mr. Baker is in charge of these instruments. From the first two of these instru-

ments traces in duplicate are obtained, one set being sent to the Meteorological Office and one retained at Kew; as regards the Anemograph, the original records are sent, while a copy by hand of those on tracing-paper is retained. The tabulations from the curves of the Kew instruments are made by Messrs. Baker, Page, and Foster.

2. *Verification of Records.*—In order to maintain uniformity in the system of observation at the various meteorological observatories, it is arranged by the Meteorological Committee that Mr. Stewart shall personally visit all the observatories once every year, in addition to which, when necessary, some one of the Kew assistants will occasionally visit particular stations with a specific object in view. At the request of the Meteorological Committee, a system of checks has been devised by the Kew Committee for testing the accuracy of the observations made at the different Observatories. This system, with slight modifications, is now in operation*. As this revision takes place at Kew, it has been found necessary to engage an additional assistant for the purpose of undertaking it. Mr. Rigby has been engaged for this duty—Mr. Baker, Meteorological Assistant, having the general superintendence of this department.

3. *Occasional Assistance.*—In addition to devising the system of checks mentioned above, the Kew Committee have also, at the request of the Meteorological Committee, examined the subject of instrumental verifications, and it has been found that, owing to improved construction, a higher standard of excellence in meteorological instruments may be insisted upon without rejecting more than a very small percentage of those furnished by good makers.

It has therefore been resolved by the Meteorological Committee that in future the following limits of error shall be allowed in the construction of their instruments:—

Marine Barometers of the pattern adopted by the Meteorological Office.—Reject all for which the index-error at the ordinary pressure is greater than $\cdot 015$ inch, or the capacity-error greater than $\cdot 004$ inch, or for which the mercury does not fall from $1\frac{1}{2}$ inch to $\frac{1}{2}$ inch above the present pressure in a time between 3 and 6 minutes. But for *barometers purporting to be standards*, reject all for which the index-error at the ordinary pressure is greater than $\cdot 010$ inch.

Thermometers (graduated on the stem) of the pattern adopted by the Meteorological Office.—Reject all in which the largest error at any point is greater than $0^{\circ}3$, or in which any space of 10° is more than $0^{\circ}3$ wrong.

Hydrometers of the pattern adopted by the Meteorological Office.—Reject all in which the largest error at any point is greater than 1 division of the scale (equal to $\cdot 001$ sp. gr.), or in which any space of 10 divisions is more than 0.6 division wrong.

Models of Pantagraphic Apparatus, designed by Mr. Galton, have been made and experimentally used at Kew, at the desire of the Meteorological Committee, to reduce the tracings of the self-registering instruments in any desired proportions, either in length or in breadth, with a view to the ultimate publication by that Committee of all the tracings supplied by the seven Observatories in a compact volume.

It may also be mentioned, under the head of Occasional Assistance, that at the request of the Meteorological Committee, Mr. Beckley, Mechanical

* This scheme, having been extracted, with permission, from the Report of the Meteorological Committee, will be found in the Appendix to this Report.

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A. STRANGE, Lt.-Col.

[illegible]

Examined with the vouchers and found correct.

* 3rd August, 1869.

Assistant, was sent to Armagh to examine the Barograph there, and to Sandwick-manse, Orkney, to superintend the erection of an anemometer. The expenses have, on both these occasions, been repaid by the Meteorological Committee.

In conclusion, the Kew Committee desire to bring under the notice of the British Association, that the system of automatic records established and in actual work at the Kew Observatory, comprehends magnetic, barometric, and thermometric observations, as well as those of the direction and velocity of the wind, to which an electric self-recording instrument will soon be added. They think that it would be very advantageous to magnetical and meteorological science if a fully illustrated work were published descriptive of these instruments, and of the method of working them, together with the method of reductions actually employed.

J. P. GASSIOT, *Chairman*.

Kew Observatory,
15th July, 1869.

APPENDIX.

A DESCRIPTION of the MEANS adopted by the METEOROLOGICAL COMMITTEE for ensuring Accuracy in the NUMERICAL VALUES obtained from their SELF-RECORDING INSTRUMENTS.

(Extracted, with permission, from the Report of the Meteorological Committee.)

In the first Report of this Committee the principles of construction of their self-recording instruments were fully described, and enough was said to render it probable that good results would be obtained; but the final method of tabulating from the traces of these instruments was not then decided on, nor had any scheme been devised for ensuring accuracy in the tabulated numerical values.

The labours of the Committee in this department have been materially aided by suggestions from the superintending Committee of the Central (Kew) Observatory, and also from the Directors of the various outlying observatories, and as a result the Committee are now satisfied that the process of examination to which the tabulated values are subjected before reaching the central office is such as to afford a satisfactory guarantee of accuracy.

It may be a fitting sequel to the description of these instruments (already given), to give here an account of the method adopted for ensuring accuracy in the results which they afford.

In the first place, the nature of the various instrumental errors and the best method of avoiding these may with propriety be described, and in the next place it may be desirable to give in detail the code of regulations adopted by the Committee for the guidance of their various observatories.

BAROGRAPH.

The values of atmospheric pressure derived from this instrument are liable to have their accuracy affected by three causes:—

- (1) By an imperfect temperature compensation.
- (2) By a sluggish action of the mercury in the Barograph tube.
- (3) By imperfection in the system of recording and tabulating.

Temperature compensation.—The method by which the Barographs are compensated for temperature has been described in the Report of the Meteorological Committee for the year 1867. The precise position of the fulcrum of the glass rod was determined by means of some preliminary expe-

periments made at Kew upon the first Barograph. These experiments consisted in subjecting the instrument to a very considerable range of temperature artificially produced, while frequent comparisons of its indications with those of a Standard Barometer gave the means of determining approximately what ought to be the position of the fulcrum. It may be presumed that the determination thus arrived at cannot be wrong more than one-tenth of the whole, and assuming this to be the case, the next point is to find what is the actual daily temperature range at the various observatories.

The following Table exhibits both the mean and the maximum daily range for each month for each of the seven observatories up to the end of 1868. In all these, with the exception of Stonyhurst, a night observation is made of the temperature of the Barograph at 10 o'clock, but the result will show that in Stonyhurst such an observation is unnecessary. It ought here to be borne in mind that from the system adopted in these instruments, namely, constant reference each day to a standard, it is only the daily range of temperature that we have to consider.

Daily range of temperature, in degrees Fahrenheit, as given by the observation hours.

1868.	Aberdeen.		Armagh.		Falmouth.		Glasgow.		Kew.		Stonyhurst.		Valencia.	
	Mean.	Maximum.	Mean.	Maximum.	Mean.	Maximum.	Mean.	Maximum.	Mean.	Maximum.	Mean.	Maximum.	Mean.	Maximum.
January	...	...	...	...	...	...	1'9	4'9	...	...	0'2	0'8	...	...
February ...	...	...	...	...	...	...	1'4	3'0	0'9	1'7	0'2	0'6	...	...
March	...	...	...	...	...	...	1'7	4'3	0'9	1'7	0'2	1'6	...	...
April	2'1	3'7	...	...	...	...	1'6	3'4	1'1	3'1	0'1	0'6	...	...
May	1'9	5'0	...	...	1'4	3'0	1'4	3'0	1'4	3'3	0'2	0'6	...	...
June	2'1	3'7	...	...	1'7	6'7	1'9	4'1	1'5	3'7	0'4	1'8	...	...
July	3'0	4'8	...	...	1'9	3'6	2'1	4'4	2'0	5'6	0'8	3'0	...	...
August	1'9	3'2	1'7	3'9	1'7	2'8	1'9	4'8	2'7	7'0	0'5	1'3	1'4	2'5
September ...	2'3	4'6	1'8	3'8	1'8	6'3	2'2	7'3	2'4	8'7	0'5	1'2	1'2	2'6
October	1'5	2'5	1'9	3'6	1'4	3'0	2'0	6'0	0'8	1'8	0'6	2'7	1'2	2'7
November ...	2'1	3'7	1'9	3'6	1'4	2'8	1'3	3'1	1'0	1'9	0'7	1'3	1'2	2'4
December ...	2'0	6'3	1'4	2'2	1'1	2'3	1'3	4'9	0'9	2'5	0'7	2'4	1'0	4'3

From the results of this Table it would appear that, assuming the temperature adjustment to be one-tenth wrong, the greatest error introduced from this cause into any of the observations during the year 1868 would be about 0'0024 in., while the mean monthly error would be inappreciable in all cases.

We may therefore with confidence presume that in these Barographs the method of tabulation exemplified in the Report for 1867 and now practised is sufficiently accurate to obviate all effects of changes of temperature, and that it is unnecessary to resort to that more complicated but perfect system of reduction alluded to in the same Report, by which the influence of temperature may be completely eliminated. The near correspondence between the simultaneous Standard and Barograph readings, as exhibited in page lvii of this Report, is another proof that the temperature correction is practically perfect.

Sluggishness of Mercury.—As the Barograph tube is always in perfect

repose, and the adhesion of the mercury to the glass is not counteracted by tapping or moving the tube, it is desirable to test the results obtained in order to see if the influence of adhesion causes a perceptible sluggishness of the mercury. The Standard Barometers, to which in all cases the Barographs are referred, are, on the other hand, subject to motion, and are probably sufficiently moved in the operation of reading to counteract any sluggishness of the mercury.

Now, four or five times each day, while the light is cut off from the recording cylinder of the Barograph by the clock arrangement, the Standard Barometer is read. We can thus compare these standard readings with the simultaneous measurements of the Barographs, these latter being of course properly tabulated, converted into true inches, and the residual correction applied as described in the Report of the Meteorological Committee for 1867.

Should there be any sluggishness in the mercury of the Barograph we might expect to discover it by means of this comparison, for in such a case the Barograph would lag behind, and thus read too low with a rising and too high with a falling barometer.

If therefore we presume that the Standard Barometer is free from sluggishness, and denote its readings by *S*, and those of the Barograph by *B*, then *S*—*B* ought in the case of sluggishness of the Barograph to be *positive* for a *rising* and *negative* for a *falling* barometer.

Several months' observations have been discussed in this manner for each of the observatories, and the result is exhibited in the following Table :—

Name of Observatory.	Months used.	<i>S</i> — <i>B</i> (Barometer rising).	<i>S</i> — <i>B</i> (Barometer falling).
		in.	in.
Aberdeen	July to December	+0'00033	—0'00028
Armagh	September to December ...	+0'00045	—0'00032
Falmouth	August to December	+0'00006	—0'00020
Glasgow	July to December	+0'00027	—0'00025
Kew	January to June	+0'00027	—0'00019
Stonyhurst	January to June	—0'00042	+0'00058
Valencia	August to November	+0'00005	+0'00015

From this Table we see how inappreciable in all the observatories is the retardation of the Barograph Barometer as compared with the Standard, while in Stonyhurst the Standard even appears to be a trifle more retarded than the Barograph Barometer.

Errors of recording and tabulating.—Under this head we may include (A) errors of adjustment and attachment of paper, (B) errors of time and date, (C) errors in tabulating from the traces. To begin with the first of these :—

(A) *Errors of adjustment and attachment of paper.*

Want of definition arising from an improper adjustment of the lens ought to be noticed, but it is believed that the definition is good in the case of all the observatories. As the instrumental constants for all the various Barographs have now been determined, it would hardly seem expedient to alter the position of the lens, which would alter these constants, for the purpose of procuring greater perfection in definition.

The photographic sheet which is attached to the cylinder of the Barograph

ought to be evenly put on without any *bagging* or *bulging*; as, if it bulged, besides giving a bad result, it might come into contact with the end of the temperature adjustment bar.

Care ought to be taken that there is no *want of light*, especially in the case of a low barometer; and finally, great precaution should be taken to avoid *finger-marks* and every species of *bad photography*.

(B) *Errors of Time and Date.*

Suppose that the sheet has been placed in an unexceptionable manner upon the Barograph cylinder, the next point is for the operator to set the instrumental clock before starting to correct Greenwich mean time, as given by his chronometer. Now the instrumental clock has an arrangement for cutting off the light for four minutes every two hours, beginning to do so two minutes before an even hour and ending two minutes after it, and the practice is for the observer to read the Standard Barometer about five times every day at periods two minutes after even hours, as ascertained by his chronometer, or when the light should be about to be restored after having been cut off by the clock-stop. If therefore the instrumental clock keeps good time and its stop acts, and if the observer reads the Standard Barometer correctly and at the proper moment as ascertained by his chronometer, and if he finally reduces his curves properly, the near coincidence between the corresponding curve and Standard readings will be a good practical test, not only that all these operations have been properly performed, but also that throughout the curve the instrumental clock keeps good time with the chronometer. A further check with regard to time is afforded by the comparison made between the chronometer and the instrumental clock at the moment when the curve is taken off the cylinder, the results of which are recorded on the curve.

The clock may sometimes possibly stop, or the clock-stop may go wrong. Without discussing minutely these possibilities, it may be sufficient to state that when any such misadventure occurs the curve ought to be inspected by the Director of the Central Observatory.

There still remains the question of *date*. The security that a curve is rightly dated depends ultimately on the strong improbability that an observer at any of the observatories should make a mistake with regard to the first day of the week. When therefore he returns the Barograph journal filled up, we may be quite certain that the observations entered on the line with Sunday were really made on that day, although he may possibly put the wrong day of the month on the form beside it.

Again, the photographic operator when he takes off a curve, should mark on the back in pencil the day of the week and month when the curve was taken off, and should also, after drying, write upon its face the hour and day of putting on and taking off as recorded by the journal. If, therefore, the accuracy of the observer in assigning the proper day of the month to Sunday be checked at Kew as each week's journals are transmitted to that establishment, and if it also be seen that the date written in pencil on the back of the curve corresponds to that written on its face, and if the times of starting and ending of the curve as described in front are found to agree with the curve itself as measured by a simple time-scale, there can hardly be any doubt that the curve has been properly dated; if there still remain any doubt it will be dispelled when the tabulations from that curve are examined and it is found that the tabulated readings agree well with the simultaneous readings of the Standard Barometer.

(C) *Errors in tabulating from the traces.*

It will, in the first place, be necessary to discuss some arrangement for ensuring the entry under the *proper date* into the tabulation forms of the measurements from each curve; for even supposing that by the method now described we can ensure the proper dating of the curve, yet the tabulations from this curve may be entered under the wrong date in the tabulation form.

The appropriate check would seem to be the independent entry from the journal of the Standard readings reduced. For if either of these two independent entries be wrongly made, this will be seen by a non-coincidence of the reduced readings when compared with the simultaneous Standard readings. Our security becomes, therefore, the security which we have that these two independent readings cannot both be erroneously entered, and this may be converted into a certainty if the assistant at the Central Observatory sees that the journal readings are entered under their proper dates into the Barograph tabulation forms.

Having thus ascertained the entry into the tabulation forms under their proper dates of the tabulations and of the reduced standard readings, we come next to inquire what check there is for *accuracy of tabulations*; and here we may consider separately the cases of large and small errors.

But before proceeding to this part of the subject it may be desirable to say a few words regarding the system of Barograph tabulation.

The progress made in tabulating the Barograms up to the date of publication of the last Report of the Committee has been described in that Report. The first operation is to measure by the aid of a simple tabulating instrument, carrying a scale with a vernier attached to it, and capable of being read to the thousandth of an inch, the whole depth of the Barogram for every hour.

This system is nevertheless laborious, implying two measurements and one subtraction for each hour, besides the application of tables of conversion, and the consequence is the liability to make an occasional mistake. But although at first it is absolutely necessary to have in the case of the Barograph a tabulating instrument measuring inches, in order by its means to determine the constants of each instrument, yet when once these instrumental constants have been accurately determined, it has been found serviceable to replace the tabulating instrument by another which gives the true pressure in one measurement, instead of requiring two measurements, one subtraction and one conversion. Instruments of this nature have been obtained by this Committee for their various observatories, by which the labour of tabulation has been greatly reduced and accuracy of result much increased.

Nevertheless there is still the liability to make an occasional blunder, and as this may take the shape of a large error, it is necessary to devise some means for detecting and obviating all such mistakes.

The best remedy appears to be the use of a simple kind of subsidiary tabulating instrument, consisting of an ivory scale having a breadth equal to one hour of the time-scale, by means of which the hourly depth of the Barogram may be read to the hundredth of an inch. If these readings be compared with the readings taken independently by the tabulating instrument, any error in the latter will be at once discovered; for the errors to which the tabulated measurements are liable are such as *five hundredths of an inch*, or *one-tenth of an inch*,—errors of a large size, which may easily be detected by the system of subsidiary measurement.

The following is an example of a day's comparison after this method, exhibiting an error which has thus been brought to light:—

August 20th.	Tabulated reading from weekly tabu- lation sheet to the nearest hundredth. A.	Subsidiary ta- bulation with ivory scale. B.	A—B in hundredths of an inch.
1 A.M.	30'22	30'21	+1
2 "	'22	'22	0
3 "	'21	'21	0
4 "	'22	'23	-1
5 "	'22	'22	0
6 "	'23	'22	+1
7 "	'24	'24	0
8 "	'25	'25	0
9 "	'25	'25	0
10 "	'26	'26	0
11 "	'26	'27	-1
Noon	'26	'27	-1
1 P.M.	'25	'25	0
2 "	'25	'25	0
3 "	'26	'27	-1
4 "	'25	'26	-1
5 "	'25	'25	0
6 "	'24	'34	-10 Error.
7 "	'24	'24	0
8 "	'24	'25	-1
9 "	'25	'26	-1
10 "	'24	'24	0
11 "	'24	'24	0
Midnight	30'24	30'25	-1

It ought to be remarked as necessary to the completeness of the check, that the observer should first of all by means of his subsidiary ivory scale fill in column B, and then (meanwhile concealing B from his view) fill in column A from the ordinary tabulation sheets. The correctness of the column A—B should be tested at the Central Observatory.

Having by this means obtained correct tabulations, the next point is to check the accuracy with which the *residual correction* has been obtained and applied (see Report for 1867, page 46). And first, with regard to the method by which it is obtained, the latest practice has been to calculate it for each day separately, making the day begin at 11 A.M. The advantage of this arrangement is that each fresh paper, which is always put on between 10 and 11 A.M., will have its own residual correction*. The accuracy of calculation of this correction ought to be checked, and such a check may be devised out of the practice pursued at Kew, of taking the mean monthly difference between simultaneous readings of the Standard and Barograph readings corrected. If these differences are taken for each day apart, beginning the day at 11 A.M. and giving each difference its appropriate sign, then the residual correction may be presumed to be accurate, when for that day there are as many *minus* as *plus* differences. Also, when any such difference exceeds, say, .005 of an inch, the accuracy with which the

* A special arrangement regarding the residual correction has been made for Sundays and those days on which there are few observations of the Standard Barometer.

Standard readings have been reduced to 32° ought in this case to be examined. When a Standard reading is evidently wrong it ought to be noted as such on the curve, and should not be made use of either in calculating the residual correction or the monthly mean difference between the Standard and Barograph readings. By applying both the above tests any error in the calculation of the residual correction will be detected, and ought to be remedied at once. Having by this means obtained an accurately calculated residual correction, the accuracy with which this is applied to the various hours ought to be tested by the Kew assistant, who, obscuring from his view the column which embodies the values after the residual correction has been applied, should independently apply it on a separate piece of paper, thus producing a new column of corrected pressure, which ought to be compared with the old one; any error discovered by this comparison should be corrected at once. Before leaving this subject, it ought to be stated that the tabulating instrument as well as the subsidiary ivory scale are so arranged as always to ensure reading the proper point of the curve for every odd hour.

Should any portion of the curve be too *faint* for measurement with the ordinary tabulating instrument, but not too faint for measurement with the ivory scale, it ought to be measured with this scale, applying to the measurements so obtained their own appropriate residual correction. Such readings ought to be specially noted in the tabulation forms.

Should any part of the curve be *deficient from want of light or any other cause*, it ought not to be inked in. If the deficiency be in the border of the temperature curve, it will be possible to correct it, but if it be in the barometric curve, this cannot be done.

All curves in which the *clock has stopped or the clock-stop has been out of action*, should be personally inspected by the Director of the Central Observatory, in order that he may ascertain if the tabulations have been properly made.

Finally, it is right to state that the accuracy of the method of checking the tabulated values now described, has been practically confirmed by the month of October at Kew being independently measured by two observers. The results of the two sets, when compared together, are found to differ very slightly from one another, the greatest difference being $\cdot008$ in., which may be supposed to denote a difference in each of $\cdot004$ on either side of the truth. This extreme difference only occurs three times in the course of the month, that is to say, in 744 observations.

The method of subsidiary tabulations now described is thus proved to be effective in discovering the larger errors that the observer is liable to make when he measures the curve. But to ensure an efficient standard of correctness, it is not only necessary that the larger errors should be altogether eliminated, but *smaller errors* should be reduced to a minimum. Thus an observer might be sufficiently cautious in reading his scale to make no large error, yet sufficiently incautious to read erroneously when he came to the third figure of decimals. For rough results such an observer might be reckoned a good one, but for the more delicate class of investigations his figures would be of less value.

The only way of perfectly eliminating this class of errors is for two independent observers to make separate measurements, each with a tabulating instrument, a course involving much additional labour and expense. But it is obvious that the Standard Barometer affords a ready approximate means of estimating the correctness of an observer's results. For should he be an incautious observer, the mean difference between the simultaneous readings

of the Standard and the Barograph Barometer will be comparatively great, but if he both observe his Standard and measure his curves well, the mean difference will be small.

The following Table exhibits the results of monthly comparisons between simultaneous Barograph and Standard readings for the year 1868 for all the observatories.

Mean Differences between Barograph and Standard Readings.

	Aberdeen.	Armagh.	Falmouth.	Glasgow.	Kew.	Stonyhurst.	Valencia.
1868.	in.	in.	in.	in.	in.	in.	in.
January .....	.....	.....	.....	0'0067	0'0027	0'0032	.....
February .....	.....	.....	.....	0'0045	0'0027	0'0032	.....
March .....	.....	.....	.....	0'0039	0'0028	0'0025	.....
April	0'0035	.....	.....	0'0035	0'0027	0'0017	.....
May	0'0032	.....	0'0042	0'0036	0'0025	0'0031	.....
June	0'0029	0'0049	0'0029	0'0036	0'0021	0'0021	.....
July	0'0032	0'0045	.....	0'0026	0'0027	0'0032	.....
August	0'0031	0'0033	0'0032	0'0038	0'0025	0'0023	0'0033
September	0'0023	0'0031	0'0041	0'0031	0'0025	0'0025	0'0027
October	0'0028	0'0029	0'0024	0'0030	0'0017	0'0028	0'0031
November	0'0019	0'0024	0'0017	0'0029	0'0015	0'0019	0'0038
December	0'0022	0'0022	0'0022	0'0028	0'0018	0'0030	0'0033

It is imagined that the mean differences shown by this Table have for all the observatories by the end of the year reached a minimum value not much larger than would be obtained by two observers reading the same Standard, or by the same observer reading it twice.

But while the simultaneous readings of the Standard and Barograph Barometer afford us one means of testing the correctness of the observation measurements, they do not yet do quite enough; for, in the first place, these simultaneous differences may be caused in part by an instrumental error or by some local peculiarity, such as rapid heaving of the barometer, and in the next place, an observer may unconsciously bestow a greater amount of pains upon these measurements, which are simultaneous with Standard readings, than he does upon his other measurements, and the above differences may not therefore be a true representative of his general correctness. A certain number of remeasurements of the curves of each observatory should therefore be made at the Central Observatory, and the monthly mean difference between these and the corresponding measurements by the local observer be recorded*.

* It was not until the various observatories had been supplied with their improved tabulating instrument that the final method of making these measurements was decided on. Since the beginning of 1869 the plan has been to make for each month for each observatory forty remeasurements of the curve at Kew, obtaining also independently the residual correction. These final values are then compared with the corresponding values obtained at the outlying observatories, and the result of this comparison for the first three months of 1869 has been as follows:—

Mean Difference between 1st and 2nd Measurements.

	Aberdeen.	Armagh.	Falmouth.	Glasgow.	Kew.	Stonyhurst.	Valencia.
1869.	in.	in.	in.	in.	in.	in.	in.
January	0'0020	0'0017	0'0026	0'0022	0'0012	0'0029	0'0017
February	0'0030	0'0025	0'0023	0'0022	0'0023	0'0031	0'0026
March	0'0024	0'0021	0'0025	0'0026	0'0018	0'0030	0'0025

THERMOGRAPH.

The accuracy of the Thermograph results is liable to be deranged by three causes :—

- (1) By a cause depending on the situation and exposure of the instrument.
- (2) By instrumental deficiencies, and especially the arrangements connected with the wet bulb.
- (3) By a deficient system of tabulation.

Situation of Instruments.

The situation of their various Thermographs was a point carefully considered by the Meteorological Committee, and there is no reason to think that the effect of local peculiarity is considerable in the case of any of their instruments.

In the Report for 1867 this subject was alluded to, and the result of simultaneous comparisons made at Kew between the readings of two sets of dry and wet bulbs was given for the month of February, one of these sets being placed in a frame detached from the main building of the observatory, and the thermometers having very small bulbs, the other set being the wet- and dry-bulb Standard Thermometers of the Thermograph frame.

The result seemed to indicate that the local peculiarity of either frame was comparatively small; indeed, taking the average of the month, there was no residual difference between the dry bulbs, while, on the whole, the Thermograph wet bulb stood $0^{\circ}12$ higher than the other.

A similar comparison made for the month of July gave no residual difference either for the dry or wet bulbs.

Dr. Robinson, of Armagh, has likewise made a similar comparison between his Thermograph dry bulb and another Thermometer placed at a higher elevation, and has obtained as the result of 150 observations made during the months of April and May, a mean difference indicating that the Thermograph Thermometer read on the whole $0^{\circ}27$ less than the other. While this difference is not large, Dr. Robinson is of opinion that the upper thermometer is more liable to be affected by the sun, and that the Thermograph Thermometer is in consequence the most correct. No other observations have been made on the subject.

Instrumental Deficiencies.

The *wet-bulb arrangements* are peculiarly liable to go wrong, and the following course of action is suggested in order to reduce this source of error to a minimum.

The Standard Thermometers should be read at least five times a day at those moments when the light is cut off by the clock arrangement. The light remains cut off by this arrangement for four minutes, and it is necessary to read the Standard Thermometers *at the beginning* of this interval; the exact points in the curves corresponding to certain known readings of the Standards may thus be determined. When the Standards are read, the observer ought to notice if both wet bulbs are acting properly. If both are right, the sign $\surd$ should be made after the recorded temperature of the wet Standard. If the Thermograph wet bulb is wrong, the sign i should be made, and if the Standard wet bulb is wrong, the sign s . Either wet bulb, if found wrong, ought to be put right at once. Should it happen that the wet bulbs are frozen at the moment of observation, the present temperature

being also below 32° , cold water should be poured over the wet bulbs and the connecting strings. In a few minutes the wet bulbs will by this means be covered with a fresh coating of ice; this should be repeated if necessary. If this operation is performed two or three times a day during very cold weather, there is reason to believe that the wet bulb will always be covered with a sufficient coating of ice. But if the wet bulb and the water of the water-vessel be frozen from previous cold, the present temperature being above 32° , the ice of the water-vessel may be thawed by warm water, using no more than is necessary for the purpose.

If these regulations be followed during the cold months of the year, it is believed that there are comparatively few instances where we may not know the temperature of evaporation during frost.

During dry weather the wet-bulb arrangement is again liable to go wrong, although from a different cause. The thread, which in the arrangement adopted lies along a copper groove, gets dry in its passage from the water-vessel to the bulb, the capillary action ceasing. Sometimes it apparently rights itself without aid, but sometimes it continues wrong until it is put right at the next observation hour. The commencement and termination of such a wrong state of the wet bulb are generally so clearly indicated by the curve itself, that there appears to be little or no uncertainty in ascertaining what observations ought to be rejected. This action would best appear to be prevented by the use of an india-rubber tube lying along the metallic groove, and having one end dipping into the water of the water-vessel; and through this tube the thread ought to be carried in its passage from the water-vessel to the thermometer. Evaporation is thus avoided, and the arrangement will probably answer in winter. When the supply of water is too rapid, it may be easily and safely altered by turning up the tube.

Even when the action of the wet bulb is unexceptionable, water must frequently be added to the water-vessel. It is usual for this water to have the temperature of the air; but in cases of a great difference between the two bulbs, this will be much above the temperature of evaporation; the consequence is found to be, that in such cases there is a rise in the wet-bulb curve which, in extreme cases, may not completely right itself until a quarter of an hour has elapsed. This can only be remedied by each observatory doing all in its power to ensure that under such circumstances the water supplied to the water-vessel shall represent as nearly as possible the temperature of the wet bulb at that moment, and also that the supply of water from the water-vessel to the wet bulb shall be no greater than is necessary to keep the bulb thoroughly damp without dripping.

With regard to other deficiencies, it will only be necessary to remark here such as are peculiar to the Thermograph, since all those common to this instrument and the Barograph have already been stated under the head of the latter.

In the first place, it should be noticed that there is sufficient *light* to illuminate the whole range of the curve in a proper manner. In order to ensure this, and at the same time procure the best possible definition, the heights of the thermometers may, as occasion requires, and without detriment to the instrument, be altered so as to bring the mean temperature of the time into a central position with respect to the lens and light. This change ought, however, to be made as seldom as possible (perhaps twice or thrice in a year), and when made great care ought to be taken that there is no strain upon the wet-bulb Thermometer through tightness of the thread, whether arising from frost or any other cause.

Errors in Trace and Tabulation.

The arrangement proposed for ensuring the entry under the *proper date* into the tabulation forms of the measurements of the Thermograph curves, and of the Standard readings corrected, is almost precisely the same as that stated in the case of the Barograph.

Having ascertained the entry into the tabulation forms under their proper dates of the tabulations, and of the Standard readings corrected, we come in the next place to consider the check upon *accuracy of tabulation*, and here, as in the case of the Barograph, it will be necessary to consider separately large and small errors.

In the first place, with respect to *large errors*, in order to prevent entirely their occurrence, it is necessary to resort to the system of subsidiary tabulations. An instrument for this purpose has been devised at Kew. It is unnecessary here to state its principle of construction; suffice it to say, that the results furnished by it are used in the same manner as in the case of the Barograph ivory scale already mentioned. By this means correct columns of tabulated readings may be obtained. Again, with regard to the *Standard readings*, all that appears to be necessary is to examine both the accuracy of entry of the Standard reading corrected, and the accuracy of tabulation for all those cases in which the recorded Thermograph temperature is more than half a degree different from the corresponding Standard reading, and to make any correction that may be found to be necessary. When a Standard reading is evidently wrong, it ought to be noted as such on the curve, and should not be made use of in calculating the monthly mean difference between Standard and Thermograph readings. Before leaving this subject, it ought to be stated that the tabulating instrument as well as the subsidiary scale, are both so arranged as to ensure reading the proper point of the curve for every odd hour.

It ought to be noted that, in tabulating from the Thermograph curves, the tabulating instrument should be set from those observation hours where there is little thermometric fluctuation.

All the dry-bulb readings ought to be compared with the corresponding wet-bulb ones, and should the latter ever appear higher than the former, the case ought to be marked.

The *maximum* and *minimum* temperatures furnished by the outlying observatories ought to be checked.

All *large errors* may, it is hoped, be completely obviated by the means now described.

With regard to *small errors*, the plan adopted is the same as that for the Barograph, viz.:—

- (1) To record the monthly mean difference between the simultaneous Standard and Thermograph readings.
- (2) To make forty remeasurements from each month's curves at Kew.

The following Table exhibits the results of the method employed for testing the accuracy of the Thermograph tabulations as regards small errors:—

	Aberdeen.				Aronagh.				Falmouth.				Glasgow.				Kew.				Stonyhurst.				Valencia.					
	Mean Difference between Thermo-graph and Stan-dard readings.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.		Mean Difference between first and second measure-ments made.	No. of remeasure-ments made.	Mean Difference between first and second measure-ments.			
1868.	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
January	dry.	wet.	...	...	...	dry.	wet.	...	...	...	dry.	wet.	...	...	...	dry.	wet.	...	...	...	dry.	wet.	...	...	...	dry.	wet.	...	...	...
February ..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
March ..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
April	17 '16	12 '15	'15	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
May	18 '18	12 '16	'12	12 '12	12 '10	12 '13	12 '12	12 '10	12 '12	12 '11	12 '08	12 '12	12 '11	12 '08	12 '07	12 '04	12 '07	12 '03	12 '18	12 '35	12 '09	12 '10	12 '12	12 '10	12 '12	12 '10	12 '05	12 '10	12 '05	12 '05
June	18 '17	12 '11	'12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13	12 '12	13 '13
July	15 '26	48 '16	'13	15 '16	48 '10	10 '10	10 '12	10 '10	10 '12	10 '11	10 '12	10 '11	10 '12	10 '11	10 '07	48 '15	08 '15	08 '15	48 '13	13 '13	48 '15	16 '16	...	...	...	...	...	...	...	...
August ...	14 '15	48 '16	'10	11 '16	48 '10	09 '08	14 '14	07 '10	12 '10	48 '48	08 '08	10 '12	10 '12	10 '08	05 '07	48 '04	06 '06	08 '10	48 '08	10 '10	48 '07	07 '09	48 '18	20 '20	...	...	...	...	...	
September.	11 '12	48 '08	'12	13 '14	48 '06	09 '09	09 '09	13 '14	07 '10	48 '48	08 '07	09 '09	48 '48	08 '07	08 '07	48 '04	06 '06	08 '09	48 '06	10 '10	06 '10	09 '12	48 '12	10 '10	...	...	...	...	...	
October ...	10 '13	48 '10	'13	17 '19	48 '07	07 '09	09 '09	06 '06	09 '09	48 '48	11 '11	11 '11	06 '06	06 '06	48 '48	05 '05	08 '08	08 '08	10 '10	48 '08	09 '09	12 '12	48 '08	08 '08	...	...	...	...	...	
November.	18 '14	48 '09	'12	12 '14	48 '11	09 '09	08 '07	07 '10	07 '10	48 '48	10 '13	10 '13	06 '06	06 '06	48 '48	04 '04	05 '05	08 '08	10 '10	48 '08	10 '10	10 '10	48 '08	08 '08	...	...	...	...	...	
December.	10 '11	48 '17	'11	10 '13	48 '06	09 '09	08 '07	10 '10	07 '10	48 '48	12 '09	09 '09	06 '06	06 '06	48 '48	05 '05	07 '07	08 '08	10 '10	48 '07	08 '08	11 '11	48 '04	04 '04	...	...	...	...	...	

It is believed that the results of this Table afford satisfactory evidence not only of the accuracy with which the Standard Thermometers are read, but also of the accuracy of tabulation from the traces. A tendency in the monthly mean differences to decrease from their first values at starting will be noticed in the case of all the observatories.

ANEMOGRAPH.

The accuracy of the Anemograph is, like that of the Thermograph, liable to be deranged by three causes:—

- (1) By a cause depending on the situation and exposure of the instrument.
- (2) By instrumental deficiency, such as friction.
- (3) By deficient traces and tabulations.

Situation of Instruments.

These instruments are placed on the highest points of the various observatories, and as far as possible out of the reach of local influences. The exposure may therefore be considered good in the case of all the observatories.

Instrumental Deficiencies.

Friction is the most important of these, and may be supposed to affect to a small extent both the records of direction and velocity. The axle of the direction-vane moves in a wooden bearing, which is saturated with oil. It is believed that when the instrument is regularly attended to, the friction consequent upon this arrangement can be kept very small.

As regards the influence of friction upon the velocity-records, this has been determined in the case of the Kew instrument, and also by Dr. Robinson for his Anemograph, which has been for many years in operation. The following friction coefficient has been adopted, with the concurrence of Dr. Robinson, as applicable to the records of all the Anemographs belonging to the Meteorological Committee:—

Observed.	miles.	miles.
For velocities from 0·0	0·0	} add 1·5
to 0·5	0·5	
” 1·0	1·0	} add 1·0
to 3·0	3·0	
” 4·0	4·0	} add 0·5
to 10·0	10·0	

Errors of Trace and Tabulation.

It ought to be noticed that *both the direction- and the velocity-pencils* are working well and freely on the paper.

It is also to be noticed that, for all the observatories except Falmouth, the *needle on the cylinder* goes through the centre of the crosses marked on the metallic paper.

In Falmouth the velocity-pencil is slightly out in position, and in consequence that observatory has been directed to set to a point which is not quite in the centre of the crosses. The Falmouth instrument has also been oriented for this position of setting. A note of the proper position of setting for Falmouth is preserved at Kew, and the assistant there ought to inspect each Falmouth Anemogram to see that it has been properly set.

With regard to *date*, each curve when taken off the cylinder should have both the day of the week and of the month written upon it, and when it reaches Kew it ought to be inspected by the assistant there in order to see that the observer has attached the proper day of the month alongside the day of the week.

He should also see that the week's curves sent are dated consecutively.

With regard to *time*, a prick made in the small time-scale of the metallic sheet denotes in terms of the hour-lines ruled on this sheet, the moment of starting, and a similar prick that of taking off. These pricks ought to denote the true chronometer times of starting and taking off very nearly, if the instrumental clock has been properly regulated. All *stoppages* of the instrumental *clock* ought to be marked.

It ought also to be noticed that the *cylinder is well clamped*, otherwise the friction of the pencil upon the cylinder may occasionally overcome that of the clamp, in which case the cylinder will slip.

With regard to *errors of tabulation*, the assistant at Kew ought in the first place to ascertain that the curve is tabulated under its *proper date*. Probably an intelligent inspection of the direction- and velocity-records in connexion with the tabulated results will be sufficient to determine this point.

A simple system of *subsidiary tabulations* has been adopted in order to check the direction-results. The observer at the outlying observatory is requested to write down on a separate sheet in numbers the direction of the wind at each hour as read from the curve by his eye, and compare it, as in the case of the Barograph and Thermograph, with the tabulated results. The differences between the two columns or A — B ought to be inspected at Kew, and when they are greater than *two points* the case ought to be examined, and any error detected ought to be corrected at once. With respect to direction, fractional parts of a point ought not to be recorded.

With regard to *velocity-traces*, the action of the instrument is such as to give by a glance at a curve the whole space travelled over by the wind for that day. Perhaps, therefore, it will be a sufficient check upon the velocity-records if, in addition to an intelligent comparison of the traces and tabulations, each day's results are added up and the sum total compared with that derived by glancing at the curve. When the difference between these two daily sum totals is greater than *one-twentieth of the whole*, the tabulated velocities for that day ought to be gone over again, and if any error is detected it ought to be put right at once.

It is probably unnecessary to check the recorded oscillations, as these are of inferior scientific value, and additional labour bestowed upon them would appear to be superfluous.

Finally, in order to keep a check upon *small errors*, the system of making at Kew forty remeasurements for each month, both for direction and velocity, has been adopted.

The following Table exhibits the results of the method employed for testing the accuracy of the Anemograph tabulations as regards small errors.

It will be seen from this Table that the standard of accuracy as represented by the smallness of the mean monthly differences has gradually increased up to the end of the year.

	Aberdeen.				Armagh.*				Falmouth.				Glasgow.				Kew.				Stonyhurst.				Valencia.			
	No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.		No. of re- measurements		Mean Difference.	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1868,																												
January	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
February	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
March	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
April	10	0'5	1'0	...	12	0'2	0'9	...	12	0'2	1'0	0'4	...	12	0'3	0'8	...	12	0'1	0'6	...	12	0'0	0'7	...	...	...	...
May	12	0'4	0'8	...	10	0'3	1'1	...	12	0'2	0'7	...	...	12	0'1	1'0	...	12	0'7	0'5	...	...	...	...	...	...	...	...
June	12	0'5	0'9	...	12	0'2	1'1	...	12	0'7	0'3	...	...	12	0'5	0'9	...	10	0'5	0'3	...	...	...	...	...	...	...	...
July	48	0'1	0'5	...	48	0'3	0'6	...	48	0'3	0'9	...	48	0'1	0'9	...	48	0'2	0'5	...	...	...	...	...	...	...	...	...
August	48	0'2	0'5	...	48	0'3	1'0	...	48	0'2	0'6	...	48	0'1	0'5	...	48	0'4	0'5	...	48	0'5	0'4	...	48	0'2	0'9	...
September	48	0'2	0'6	...	48	0'1	0'9	...	48	0'2	0'8	...	48	0'1	0'5	...	48	0'4	0'5	...	48	0'5	0'4	...	48	0'2	1'0	...
October	48	0'3	0'7	...	48	0'3	0'6	...	48	0'4	0'5	...	48	0'3	0'4	...	48	0'5	0'5	...	48	0'5	0'5	...	48	0'4	1'0	...
November	48	0'4	0'6	...	48	0'2	0'8	...	48	0'4	0'7	...	48	0'3	0'3	...	48	0'3	0'3	...	48	0'3	0'5	...	48	0'3	1'2	...
December	48	0'3	0'8	...	48	0'2	0'8	...	48	0'3	0'7	...	48	0'2	0'5	...	48	0'2	0'5	...	48	0'3	0'6	...	24	0'3	1'2	...

* The Anemograph of Dr. Robinson is somewhat different from the others, and it is only since the beginning of 1869 that the method of checking his results has been finally decided on.

CODE of REGULATIONS adopted by the METEOROLOGICAL COMMITTEE
for ensuring ACCURACY in the RESULTS derived from their SELF-
RECORDING INSTRUMENTS.

In the first place a set of rules have been framed for the guidance of the various observatories, including the Central Observatory at Kew. Secondly, a set of forms have been constructed on which to register the deficiencies and mistakes in the returns from the various observatories, copies of which when filled up are forwarded to the Directors of these observatories on the one hand, and to the Meteorological Office on the other. Thirdly, a diary of operations has been constructed, from which each observatory may know the times at which the various documents ought to be sent to Kew. Fourthly, each month's results are laid before the Meteorological Committee, accompanied with the remarks of the Director of the Central Observatory, which are then printed in the minutes of that body*.

REGULATIONS FOR BAROGRAPH.

Outlying Observatory.

- (1.) The curves, journals, and tabulation forms to be written upon according to the pattern furnished.
- (2.) Always begin a new month with new forms. The curves and forms are to be numbered consecutively from the beginning of the year, as will be seen from the diary.
- (3.) Clock to be set to Greenwich mean time at starting, and its error not to exceed two minutes in two days.
- (4.) The Barograph Thermometer and the Standard Barometer, and its attached Thermometer, ought to be read five times a day if possible while the light is cut off by the clock-arrangement. The light remains cut off by this arrangement for four minutes, and it is necessary to read the Standard Barometer *at the end* of this interval—the exact points in the curve corresponding to certain known readings of the Standard may thus be determined. It ought to be noticed when the Standard is heaving or oscillating.
- (5.) The instrument should always be started between 10 and 11 A.M. Greenwich mean time on those days mentioned in the diary.
- (6.) Every change made in the instrument, every stoppage of clock, &c., and all peculiarities in the curve, noticed by the observer, should be inserted in the journal under the head of "Remarks," with the exact time attached thereto. Should the height of the Barometer-cistern be altered, or any change made which will affect the curve, this ought, as already mentioned, to be noticed; it is, however, considered that all such changes ought to be avoided.
- (7.) The previous week's curves, journals, and tabulations should be sent to Kew every Thursday, as mentioned in the diary.

* In these remarks there is recorded, amongst other things, each blank in the traces during the month. The following were the blanks for February 1869:—

Anemograph (direction)	10	hourly records lost out of	4704.
Ditto (velocity)	20	" " "	4704.
Barograph.....	13	" " "	4704.
Thermograph (dry bulb).....	2	" " "	4704.
Ditto (wet bulb).....	12	" " "	4704.

Central Observatory (Assistant).

- (8.) The assistant at Kew shall examine each curve in order to see if there is any want of light or appearance of bagging, or of finger-marks, or of bad photography, and he shall occasionally see that the temperature bar is in proper action.
- (9.) He shall see that the clock and clock-stop have been in good action for the time of the curve.
- (10.) That the instrumental clock does not differ more than two minutes from the chronometer as recorded on the curve.
- (11.) That the date written on the back of the curve agrees with that on the face.
- (12.) That the curve is properly written upon after the pattern.
- (13.) That in the Barograph Journal the proper day of the month is placed alongside of Sunday, and that the others follow consecutively.
- (14.) That the times of starting and stopping the curve as recorded in the journal have been properly recorded on the face of the curve.
- (15.) Finally, he shall ascertain, by means of a simple inspection of the curve, that the beginning and ending, as shown by the curve itself, are the same as those described on the face of the curve.
- (16.) He shall see that the journal readings of the Standard Barometer are entered under their proper dates into the Barograph tabulation sheets.
- (17.) Then examine in a general manner the accordance of the Barograph and Standard readings for each day. If these two tests be satisfactory, he may conclude that the tabulations and Standard readings have both been entered under their proper dates.
- (18.) Check the accuracy of the subtractions made in the tables of subsidiary measurements furnished by the outlying observatory.
- (19.) Investigate all cases where $A - B$ is greater than $\cdot 02$ in.; if an error be revealed in the tabulations, this error ought to be corrected at once. These corrections ought to be made before the next step in the process is commenced.
- (20.) Then ascertain the accuracy with which the residual correction has been found according to the method described, and whenever it has been found necessary to alter the residual correction, a correction should also be made in the last column of the tabulation papers.
- (21.) Then check after the manner described the accuracy with which the residual correction has been applied, producing a new column of corrected pressure, which he shall compare with the old one, and any error discovered by this comparison shall be corrected at once.
- (22.) Portions of the curve too faint for the ordinary instrument, but capable of being measured by the ivory scale, shall be measured, corrected, and marked as specified.

Central Observatory (Director).

23. The assistant at Kew shall bring all curves and tabulations which exhibit deficiencies personally before the Director of the Central Observatory, and the latter shall make the necessary remarks on the curves and tabulations, or cause them to be made, and shall communicate all cases of failure to the Meteorological Committee on the one hand and to the Director of the observatory where the

failure occurred on the other, making any remark that may tend in his estimation to obviate in future the cause of failure.

- (24.) He shall also communicate as above the monthly mean differences between the Barograph readings reduced, and the simultaneous Standard readings.
- (25.) He shall also communicate as above the result of forty remeasurements for each observatory for each month, to be made at Kew, noting (1) the greatest difference, (2) the mean difference irrespective of sign, (3) the residual difference (if any), taking signs into account.

REGULATIONS FOR THERMOGRAPH.

Outlying Observatory.

- (1.) The curves, journals, and tabulation forms to be written upon according to the pattern furnished.
- (2.) Always begin a new month with new forms. The curves and forms are to be numbered consecutively from the beginning of the year, as will be seen from the diary.
- (3.) Clock to be set to Greenwich mean time at starting, and its error not to exceed two minutes in two days.
- (4.) The Standard Thermometers should be read at least five times a day at those moments when the light is cut off by the clock-arrangement. The mode of dealing with the wet bulb has been already described, p. lviii.
- (5.) The instrument should always be started between 10 and 11 A.M. Greenwich mean time, on those days mentioned in the diary.
- (6.) Every change made in the instrument, every stoppage of clock, &c., and all peculiarities in the curve noticed by the observer, should be inserted in the journal under the head of "Remarks," with the exact time attached thereto.
- (7.) The muslin and connecting threads ought to be taken off the bulbs, washed and replaced as often as they become soiled.
- (8.) The previous week's curves, journals, and tabulations should be sent to Kew every Thursday, as mentioned in the diary.

Central Observatory (Assistant).

- (9.) The assistant shall examine each curve in order to see if there is any want of light, bagging, finger-marks, bad photography, or defective action of wet bulb, during however short a space of time.
- (10.) He shall see that the clock and clock-stop have been in good action for the time of the curve.
- (11.) That the instrumental clock does not differ more than two minutes from the chronometer as recorded on the curve.
- (12.) That the date written on the back of the curve agrees with that in front.
- (13.) That the curve is properly written upon after the pattern adopted.
- (14.) That in the Thermograph Journal the proper day of the month is placed alongside of Sunday, and that the others follow consecutively.
- (15.) That the times of starting and stopping the curve as recorded in the journal have been properly recorded on the face of the curve.

- (16.) He shall ascertain, by means of a simple inspection, that the beginning and ending, as shown by the curve itself, are the same as those described in front of the curve.
- (17.) That the journal readings of the Standard Thermometer are entered under their proper dates into the Thermograph tabulation sheets.
- (18.) He shall examine in a general manner the accordance of the Thermograph and Standard readings for each day. If these two tests be satisfactory, he may conclude that the tabulations and Standard readings have both been entered under their proper dates.
- (19.) Check the accuracy of the subtractions made in the tables of the subsidiary measurements.
- (20.) Investigate all cases in which $A - B$ is greater than $0^{\circ}5$ Fahr.; and if an error is revealed, it ought to be corrected at once.
- (21.) Examine both the corrected Standard reading and the corresponding tabulated one for all those cases in which there is a difference greater than $0^{\circ}5$ between the two.
- (22.) Compare the dry-bulb readings with the corresponding wet ones, marking and examining all those cases in which the latter appear higher than the former.
- (23.) Check the accuracy of the maximum and minimum temperatures furnished by the outlying observatories.
- (24.) Record the monthly mean differences between the simultaneous Standard and Thermograph readings.
- (25.) Make forty remeasurements as specified.

Central Observatory (Director).

- (26.) The assistant at Kew shall bring before the Director of the Central Observatory all curves, with their corresponding tabulations, that are deficient from any cause, and the Director shall make the necessary remarks on the curves and tabulations, or cause them to be made, and shall communicate all cases of failure to the Meteorological Committee on the one hand, and to the Director of the observatory where the failure occurred on the other, making any remarks that may tend in his estimation to obviate in future the causes of failure.
- (27.) The Director of the Central Observatory shall also communicate as above the monthly mean differences between the simultaneous Thermograph and Standard readings, as well as the result of the forty remeasurements made at Kew.

REGULATIONS FOR ANEMOGRAPH.

Outlying Observatory.

- (1.) The curves and tabulation forms to be written upon according to the patterns furnished.
- (2.) Always begin a new month with new tabulation forms. The curves and forms are to be numbered consecutively from the beginning of the year, as will be seen from the diary.
- (3.) The pricks on the curve, when compared with the Greenwich mean times of commencement and taking off, ought to agree with the latter within five minutes at each end.

- (4.) The curve should be taken off at 10^h 30^m A.M., and a new one replaced if possible at 10^h 32^m, Greenwich mean time.
- (5.) Every change made in the instrument, every stoppage of clock, &c., and all peculiarities in the curve noticed by the observer, should be recorded on the blank part of the sheet of metallic paper, with the exact time attached thereto. The orientation should be tested once a month.
- (6.) The previous week's curves and tabulations should be sent to Kew every Thursday, as recorded in the diary.

Central Observatory (Assistant).

- (7.) The assistant at Kew shall examine each curve in order to see if both pencils work well and freely, and if the paper has been accurately attached to the cylinder, and if the cylinder has not slipped.
- (8.) He shall see that the clock has been in good order during the time of the curve.
- (9.) That the curve is properly written upon after the pattern adopted.
- (10.) That in the writing upon the curve the proper day of the month is placed alongside the day of the week.
- (11.) That the times of putting on and taking off as recorded by the pricker do not differ more than five minutes from the chronometer time.
- (12.) He shall inspect the direction- and velocity-curves in connexion with the tabulated results, in order to ascertain that each curve is tabulated under its proper date.
- (13.) Check the accuracy of the subtractions made in the tables of the subsidiary direction measurements.
- (14.) Examine all cases in which A — B is greater than *two points*, and if an error is revealed it ought to be corrected at once.
- (15.) Check the accuracy of the velocity tabulations, according to the method herein indicated.
- (16.) Make forty remeasurements for each month, both for direction and velocity, as in the case of the other instruments.

Central Observatory (Director).

- (17.) The assistant at Kew shall bring before the Director of the Central Observatory all curves, with their corresponding tabulations, that are deficient from any cause, and the Director shall make the necessary remarks on the curves and tabulations, or cause them to be made, and shall communicate all cases of failure to the Meteorological Committee on the one hand, and to the Director of the observatory where the failure occurred on the other, making any remarks that may tend in his estimation to obviate in future the causes of failure.
- (18.) The Director of the Central Observatory shall also communicate as above the result of the forty remeasurements made at Kew.

I.—WEEKLY FORM FOR REGISTERING DEFICIENCIES.

 BAROGRAMS, &c.

(Received at Kew, _____.)

Tabulation No.
and corresponding
Documents.

Points noticed at Kew.	Results and Remarks.
1. Deficiency in number of documents sent . . . 2. Errors in numbering and writing upon them . (A.) Want of light in curves (B.) Bagging in do. (C.) Finger-marks, &c., in do. 3. Action of clock 4. Regulation of do. (D.) Action of clock-stop 5. Errors in dating curves (E.) Do. in entry or date of entry of journal readings of standard into tabulation sheets 6. Do. in date of entry of tabulated readings into tabulation sheets 7. Do. of subtraction in subsidiary tables 8. Do. of tabulation discovered by subsidiary tables (c.) Do. in calculating residual correction (d.) Do. in applying residual correction 9. Ten remeasurements (1.) <i>Greatest difference</i> (2.) <i>Mean difference irrespective of sign</i> (3.) <i>Residual difference</i>	

II.—WEEKLY FORM FOR REGISTERING DEFICIENCIES.

THERMOGRAMS, &c.

(Received at Kew, _____.)

Tabulation No.
and corresponding
Documents.

Points noticed at Kew.	Results and Remarks.
1. Deficiency in number of documents sent . . . 2. Errors in numbering and writing upon them . (A.) Want of light in curves (B.) Bagging in do. (C.) Finger-marks, &c., in do. (a.) Defective action of wet bulb 3. Action of clock 4. Regulation of do. (D.) Action of clock-stop 5. Errors in dating curves (E.) Do. in entry or date of entry of journal readings of standard into tabulation sheets 6. Do. in date of entry of tabulated readings into tabulation sheets 7. Do. of subtraction in subsidiary tables . . . 8. Do. of tabulation discovered by subsidiary tables (b.) Do. in maxima and minima 9. Ten remeasurements (1.) <i>Greatest difference</i> (2.) <i>Mean difference irrespective of sign</i> . . . (3.) <i>Residual difference</i>	

III.—WEEKLY FORM FOR REGISTERING DEFICIENCIES.

ANEMOGRAMS, &c.

(Received at Kew, _____.)

Tabulation No.
and corresponding
Documents.

Points noticed at Kew.	Results and Remarks.
1. Deficiency in number of documents sent . . . 2. Errors in numbering and writing upon them . (e.) Action of pencils (f.) Errors of attachment of paper (g.) Slipping of cylinder 3. Action of clock 4. Regulation of do. 5. Errors in dating curves 6. Do. in date of entry of tabulated readings into tabulation sheets 7. Do. of subtraction in subsidiary tables 8. Do. in direction discovered by subsidiary tables . (h.) Do. in velocity discovered by subsidiary arrange- ment 9 (a.) Ten remeasurements (<i>direction</i>) (1.) <i>Greatest difference</i> (2.) <i>Mean difference irrespective of sign</i> (3.) <i>Residual difference</i> 9 (b.) Ten remeasurements (<i>velocity</i>) (1.) <i>Greatest difference</i> (2.) <i>Mean difference irrespective of sign</i> (3.) <i>Residual difference</i>	

Specimen of Diary of Operations for 1869. **JANUARY.**

Day of Month.	Day of Week.	No. of Bar. and Ther. sheets taken off this day.	No. of Anem. sheet taken off this day.	No. of Journals and Tabulations ending this day.	Send to Kew.				Remarks.
					Bar. and Ther. Curves, Nos. inclusive.	Anem. Curves, Nos. inclusive.	Journals and Tabulations, Nos.	Weather Report for	
1.	Friday ...	1	1						
2.	Saturday...	.....	2	1					
3.	Sunday...	2-3	3						
4.	Monday ...	.....	4						
5.	Tuesday ...	4-5	5						
6.	Wednesday	.....	6						
7.	Thursday..	6-7	7	...	1 to 3	1 to 3	1		
8.	Friday ...	.....	8						
9.	Saturday...	8-9	9	2					
10.	Sunday...	.....	10						
11.	Monday ...	10-11	11						
12.	Tuesday ...	.....	12						
13.	Wednesday	12-13	13						
14.	Thursday..	.....	14	...	4 to 11	4 to 10	2		
15.	Friday ...	14-15	15						
16.	Saturday...	.....	16	3					Kew to send in documents for December 1868 to the central office.
17.	Sunday...	16-17	17						
18.	Monday ...	.....	18						
19.	Tuesday ...	18-19	19						
20.	Wednesday	.....	20						
21.	Thursday..	20-21	21	...	12 to 17	11 to 17	3		
22.	Friday ...	.....	22						
23.	Saturday...	22-23	23	4					
24.	Sunday...	.....	24						
25.	Monday ...	24-25	25						
26.	Tuesday ...	.....	26						
27.	Wednesday	26-27	27						
28.	Thursday..	.....	28	...	18 to 25	18 to 24	4		
29.	Friday ...	28-29	29						
30.	Saturday...	.....	30	5					
31.	Sunday...	30-31	31	6					

FEBRUARY.

Day of Month.	Day of Week.	No. of Bar. and Ther. sheets taken off this day.	No. of Anem. sheet taken off this day.	No. of Journals and Tabulations ending this day.	Send to Kew.				Remarks.
					Bar. and Ther. Curves, Nos. inclusive.	Anem. Curves, Nos. inclusive.	Journals and Tabulations, Nos.	Weather Report for	
1.	Monday ...	.....	32						
2.	Tuesday ...	32-33	33						
3.	Wednesday ...	.....	34						
4.	Thursday..	34-35	35	...	26 to 31	25 to 31	5		
5.	Friday ...	.....	36						
6.	Saturday ..	36-37	37	7					
7.	Sunday...	.....	38						
8.	Monday ...	38-39	39						
9.	Tuesday ...	.....	40						
10.	Wednesday	40-41	41						
11.	Thursday..	.....	42	...	32 to 39	32 to 38	6 and 7	January	
12.	Friday ...	42-43	43						
13.	Saturday ..	.....	44	8					
14.	Sunday...	44-45	45						
15.	Monday ...	.....	46						
16.	Tuesday ...	46-47	47						
17.	Wednesday	.....	48						
18.	Thursday..	48-49	49	...	40 to 45	39 to 45	8		
19.	Friday ...	.....	50						
20.	Saturday ..	50-51	51	9					
21.	Sunday...	.....	52						{ Kew to send in January documents to the central office.
22.	Monday ...	52-53	53						
23.	Tuesday ...	.....	54						
24.	Wednesday	54-55	55						
25.	Thursday..	.....	56	...	46 to 53	46 to 52	9		
26.	Friday ...	56-57	57						
27.	Saturday ..	.....	58	10					
28.	Sunday...	58-59	59	11					

RECOMMENDATIONS ADOPTED BY THE GENERAL COMMITTEE AT THE EXETER
MEETING IN AUGUST 1869.

[When Committees are appointed, the Member first named is regarded as the Secretary, except there is a specific nomination.]

Involving Grants of Money.

That the sum of £600 be placed at the disposal of the Council for maintaining the Establishment of the Kew Observatory.

That the Committee, consisting of Dr. Joule, Sir W. Thomson, Professor Tait, Dr. Balfour Stewart, and Professor G. C. Foster, be reappointed to effect a determination of the Mechanical Equivalent of Heat; and that the sum of £50 be placed at their disposal for the purpose.

That the Committee for reporting on the Rainfall of the British Isles be reappointed, and that this Committee consist of Mr. Charles Brooke, Mr. Glaisher, Professor Phillips, Mr. G. J. Symons, Mr. J. F. Bateman, Mr. R. W. Mylne, Mr. T. Hawksley, Professor Adams, Mr. C. Tomlinson, Professor Sylvester, Dr. Pole, and Mr. Rogers Field; that Mr. G. J. Symons be the Secretary, and that the sum of £50 be placed at their disposal for the ordinary purposes of the Committee, and that a further sum of £50 be granted for the purpose of providing additional rain-gauges in certain districts where observations are not at present made.

That the Committee on Underground Temperature, consisting of Sir William Thomson, Dr. Everett, Sir Charles Lyell, Bart., Principal Forbes, Mr. J. Clerk Maxwell, Professor Phillips, Mr. G. J. Symons, Mr. Balfour Stewart, Professor Ramsay, Mr. Geikie, Mr. Glaisher, Rev. Dr. Graham, Mr. E. W. Binney, Mr. George Maw, and Mr. Pengelly, be reappointed with the addition of the name of Mr. S. J. Mackie; that Dr. J. D. Everett be the Secretary, and that the sum of £50 be placed at their disposal for the purpose.

That the Committee on the Thermal Conductivity of Metals, consisting of Professor Tait, Professor Tyndall, and Dr. Balfour Stewart, be reappointed; that Professor Tait be the Secretary, and that the sum of £20 be placed at their disposal for the purpose.

That the Committee on Tides, consisting of Sir W. Thomson, Professor Adams, Professor J. W. M. Rankine, Mr. J. Oldham, and Captain Richards, be reappointed, with the addition of the name of Mr. W. Parkes, and that they be instructed to institute as soon as possible a comparison between the results of the formulae arrived at in their reports (those of observation and those of previous methods of reduction and calculation), and that the sum of £100 be placed at their disposal for the purpose.

That the Committee on Luminous Meteors, consisting of Mr. Glaisher, Mr. R. P. Greg, Mr. E. W. Brayley, Mr. Alexander Herschel, and Mr. C. Brooke, be reappointed; and that the sum of £30 be placed at their disposal for the purpose.

That Dr. Matthiessen, Professor Abel, and Mr. David Forbes be a Committee for the purpose of continuing their researches on the Chemical Nature of Cast Iron; and that the sum of £80 be placed at their disposal for the purpose.

That Mr. R. B. Grantham, Mr. J. Bailey Denton, Mr. J. R. Harrison, Mr. J. W. Wanklyn, W. Hope, and Dr. B. H. Pavl be a Committee for the purpose of continuing their investigations on the treatment and utilization of sewage; and that the sum of £50 be placed at their disposal for the purpose.

That Sir Charles Lyell, Bart., Professor Phillips, Sir John Lubbock, Bart.,

Mr. John Evans, Mr. Edward Vivian, Mr. William Pengelly, Mr. George Busk, Mr. W. Boyd Dawkins, and Mr. W. Ayshford Sandford be a Committee for the purpose of continuing the exploration of Kent's Cavern, Torquay; that Mr. Pengelly be the Secretary, and that the sum of £150 be placed at their disposal for the purpose.

That Dr. P. M. Duncan and Mr. Henry Woodward be a Committee for the purpose of continuing their Researches on British Fossil Corals; that Dr. P. M. Duncan be the Secretary, and that the sum of £50 be placed at their disposal for the purpose.

That Mr. Henry Woodward, Dr. Duncan, Professor Harkness, and Mr. James Thomson be a Committee for the purpose of making and photographing further sections of such Mountain Limestone Fossils as require to be cut in order to display their structure; that Mr. Woodward be the Secretary, and that the sum of £25 be placed at their disposal for the purpose.

That the Rev. W. S. Symonds, Mr. Lightbody, and the Rev. J. B. La Touche be a Committee for the purpose of investigating Sedimentary deposits in the river Onny; that the Rev. J. B. La Touche be the Secretary, and that £3 be placed at their disposal for the purpose.

That Dr. Bryce, Sir W. Thomson, Mr. D. Milne-Home, and Mr. Macfarlane be a Committee for the purpose of continuing the researches on Earthquakes in Scotland; that Dr. Bryce be the Secretary, and that the sum of £4 be placed at their disposal for the purpose.

That Professor Huxley, Mr. Westroppe, and Mr. W. H. Baily be a Committee for the purpose of continuing the investigation of the fossil contents of the two Kiltoran quarries, co. Kilkenny; that Mr. W. H. Baily be the Secretary, and that the sum of £20 be placed at their disposal for the purpose.

That Mr. W. S. Mitchell, Mr. Robert Etheridge, Professor J. Morris, Mr. G. Maw, and Mr. Henry Woodward be a Committee for the purpose of continuing the investigation of the Leaf-beds of the Lower Bagshot Series of the Hampshire Basin; that Mr. Mitchell be the Secretary, and that the sum of £15 be placed at their disposal for the purpose.

That Dr. B. W. Richardson, Dr. Sharpey, and Professor Humphry be a Committee for the purpose of continuing researches on the physiological action of Organic Chemical compounds; that Dr. Richardson be the Secretary, and that the sum of £30 be placed at their disposal for the purpose.

That Mr. W. Carruthers, Professor Balfour, Dr. J. D. Hooker, and Professor Dickson be a Committee for the purpose of continuing investigations in the Fossil Flora of Britain; that Mr. Carruthers be the Secretary, and that the sum of £25 be placed at their disposal for the purpose.

That Mr. Spence Bate, Mr. Joshua Couch, Dr. McIntosh, Mr. Rowe, and Mr. J. Gwyn Jeffreys be a Committee for the purpose of continuing their research on the Marine Fauna of Devon and Cornwall; that Mr. Spence Bate be the Secretary, and that the sum of £20 be placed at their disposal for the purpose.

That Mr. George Busk, Mr. H. T. Stainton, and the Rev. H. B. Tristram be a Committee for the purpose of drawing up a record of Zoological Literature of 1869; that Mr. George Busk be the Secretary, and that the sum of £100 be placed at their disposal for the purpose.

That Mr. C. Stewart, Dr. Günther, and Mr. W. H. Flower be a Committee for the purpose of investigating the structure of the Ear in Fishes, and that Mr. Stewart draw up the Report on the subject, and that the sum of £10 be placed at their disposal for the purpose.

That Dr. Arthur Gamgee, Mr. E. Ray Lankester, and Dr. M. Foster be a Committee for the purpose of investigating the amount of Heat generated in the Blood, in the process of arterialization; that Dr. Arthur Gamgee be the Secretary, and that the sum of £15 be placed at their disposal for the purpose.

That the Metric Committee be reappointed, such Committee to consist of Sir John Bowring, The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., The Right Hon. C. B. Adderley, M.P., Mr. Samuel Brown, Dr. Farr, Mr. Frank P. Fellowes, Professor Frankland, Professor Hennessy, Mr. James Heywood, Sir Robert Kane, Professor Leone Levi, Professor W. A. Miller, Professor Rankine, Mr. C. W. Siemens, Colonel Sykes, M.P., Professor A. W. Williamson, Mr. James Yates, Dr. George Glover, Mr. Joseph Whitworth, Mr. J. R. Napier, Mr. H. Dircks, Mr. J. V. N. Bazalgette, Mr. W. Smith, Mr. W. Fairbairn, and Mr. John Robinson; that Professor Leone Levi be the Secretary, and that the sum of £25 be placed at their disposal for the purpose of being applied solely to scientific purposes, printing, and correspondence.

Applications for Reports and Researches not involving Grants of Money.

That the Committee, consisting of Mr. E. J. Lowe, Professor Frankland, Professor A. W. Williamson, Mr. Glaisher, Dr. Moffat, Mr. C. Brooke, Dr. Andrews, and Dr. B. Ward Richardson, for promoting accurate Meteorological Observations of Ozone be reappointed with the addition of the name of Sir Edward Belcher.

That Professor Sylvester, Professor Cayley, Professor Hirst, Rev. Professor Bartholomew Price, Professor H. J. S. Smith, Mr. W. Spottiswoode, Mr. R. B. Hayward, Dr. Salmon, Rev. R. Townsend, Professor Fuller, Professor Kelland, Mr. J. M. Wilson, and Mr. W. K. Clifford be a Committee (with power to add to their number) for the purpose of considering the possibility of improving the methods of instruction in elementary geometry, and that Mr. W. K. Clifford be the Secretary.

That the Committee on Electrical Standards, consisting of Professor Williamson, Professor Sir Charles Wheatstone, Professor Sir W. Thomson, Professor W. A. Miller, Dr. A. Matthiessen, Mr. Fleeming Jenkin, Sir Charles Bright, Mr. J. Clerk Maxwell, Mr. C. W. Siemens, Mr. Balfour Stewart, Dr. Joule, Mr. C. F. Varley, Professor G. C. Foster, and Mr. C. Hockin, be reappointed; and that Professor Fleeming Jenkin be the Secretary.

That Mr. W. H. L. Russell be requested to continue his Report on recent progress in the theory of Elliptic and Hyperelliptic Functions.

That Dr. Frankland and Mr. M'Leod be a Committee for the purpose of continuing their researches on the composition of the gases dissolved in deep-well water.

That Dr. Anderson and Mr. Catton be a Committee for the purpose of continuing the researches of Mr. Catton on the Synthesis of Organic Acids.

That Mr. Mallet be requested to prepare a Report on the ascertained facts of Volcanoes, on the general plan of his Report on Earthquakes.

That Mr. H. E. Dresser, Rev. H. B. Tristram, Professor Newton, Mr. J. E. Harting, and the Rev. H. Barnes, be a Committee for the purpose of continuing investigations on the desirability of establishing "a close time" for the preservation of our indigenous animals; and that Mr. H. E. Dresser be the Secretary.

That Colonel Lane Fox, Sir John Lubbock, Mr. Busk, Mr. Evans, and Mr. Stevens be a Committee for the purpose of examining the interior of Stonehenge, with instructions to apply to Sir Edward Antrobus for permission to do so.

That the Committee on Agricultural Machinery, consisting of the Duke of Buccleuch, the Rev. Patrick Bell, Mr. David Greig, Mr. J. Oldham, Mr. William Smith, C.E., Mr. Harold Littledale, The Earl of Caithness, Mr. Robert Neilson, Professor Rankine, Mr. F. J. Bramwell, Professor Willis, and Mr. Charles Manby, be reappointed; and that Messrs. P. Le Neve Foster and J. P. Smith be the Secretaries.

That the Committee on Boiler Explosions, consisting of Mr. W. Fairbairn, Mr. Joseph Whitworth, Mr. Lavington E. Fletcher, Mr. F. J. Bramwell (with power to add to their number), be reappointed with a view to their considering and reporting on any legislative measures which may be brought forward in reference to the prevention of steam-boiler explosions.

Involving Applications to Government.

That the President of the British Association, the President of the Geological Section, and Mr. Godwin-Austen, Vice-President of the Section, be a Committee for the purpose of calling the attention of Her Majesty's Government to the importance of completing, without delay, the valuable investigation into the composition and geological distribution of the Hematite Iron Ores of Great Britain and Ireland, which has been already in part published in the Memoirs of the Geological Survey.

That the Committee on the Laws regulating the Flow and Action of Water holding solid matter in suspension, consisting of Mr. T. Hawksley, Professor Rankine, Mr. R. B. Grantham, Sir A. S. Waugh, and Mr. T. Login, be reappointed, with authority to represent to Government the desirability of undertaking experiments bearing on the subject.

That the Committee appointed to report on the state of existing knowledge on the *stability, propulsion and sea-going qualities* of ships, and consisting of Mr. C. W. Merrifield, Mr. Bidder, Captain Douglas Galton, Mr. F. Galton, Professor Rankine, Mr. W. Froude, be reappointed; and that they be instructed to apply to the Admiralty to make the experiments recommended in their First Report.

Communications to be printed in extenso in the Annual Report of the Association.

That Professor Magnus's communication "On the Emission, Absorption, and Reflexion of Obscure Heat," be printed *in extenso* among the Reports.

That Professor Morren's communication "On the Chemical Action of Light discovered by Professor Tyndall," be printed *in extenso* among the Reports.

That Mr. Glaisher's observations made by the Captive Balloon be published in the Proceedings.

That Mr. Frederick Purdy's paper on the "Pressure of Taxation on Real Property," be printed *in extenso* among the Reports.

That Mr. F. J. Bramwell's paper "On the laws determining the fracture of materials when sudden changes of thickness take place," be printed *in extenso* in the Report.

That Mr. Joseph Whitworth's paper "On the penetration of Armour Plates by Shells with heavy bursting charges," be printed *in extenso* in the Report.

That Mr. Thomas Login's paper "On Roads and Railways in Northern India as affected by the abrading and transporting power of Water," be printed *in extenso* in the Proceedings.

Resolutions referred to Council by the General Committee at Exeter.

That the following Resolutions be referred to the Council for consideration and action if it seem desirable :—

(1) That the Council be requested to take into their consideration the existing relations between the Kew Committee and the British Association.

That the full influence of the British Association for the Advancement of Science should at once be exerted to obtain the appointment of a Royal Commission to consider—

1. The character and value of existing institutions and facilities for scientific investigation, and the amount of time and money devoted to such purposes.
2. What modifications or augmentations of the means and facilities that are at present available for the maintenance and extension of science are requisite; and,
3. In what manner these can be best supplied.

(2) That Professor R. B. Clifton, Mr. Glaisher, the Master of the Mint, Mr. Huggins, Dr. Matthiessen, Professor W. Hallowes Miller, Dr. Balfour Stewart, Lieut.-Col. Strange, and Sir J. Whitworth, be a Committee for the purpose of reporting on Metric Standards, in reference to the communication from Professor Jacobi, appended hereto; and that the Council be empowered to petition the British Government in the name of the Association if they judge it expedient to do so.

"The Academy of Sciences of St. Petersburg, observing that the Standard Metric Weights and Measures of the various countries of Europe and of the United States differ by sensible, though small, quantities from one another, express the opinion that the continuance of these errors would be highly prejudicial to science. They believe that the injurious effects could not be guarded against by private labours, however meritorious, and they have therefore recommended that an International Commission be appointed by the countries interested, to deal with this matter. They have decided to bring the subject before the Russian Government, and have appointed a Committee of their own Body, who have drawn up a careful Report containing valuable suggestions; and they have deputed Professor Jacobi to lay this Report before the British Association, and to request the Association to take action in reference to it."

(3) That the Council be requested to ascertain whether the action of Government in relation to the higher scientific education has been in accordance with the principles of impartiality which were understood to guide them in this matter; and to consider whether that action has been well calculated to utilize and develop the resources of the country for this end, and to favour the free development of the higher scientific education. That the Council be requested to take such measures as may appear to them best calculated to carry out the conclusions to which they may be led by these inquiries and deliberations.

(4) That the rules under which Members are admitted to the General Committee be reconsidered.

Synopsis of Grants of Money appropriated to Scientific Purposes by the General Committee at the Exeter Meeting in August 1869. The names of the Members who would be entitled to call on the General Treasurer for the respective Grants are prefixed.

<i>Kew Observatory.</i>	£	s.	d.
The Council.—Maintaining the Establishment of Kew Observatory.....	600	0	0

Mathematics and Physics.

*Joule, Dr.—Remeasurment of the Dynamical Equivalent of Heat (renewed)	50	0	0
*Brooke, Mr.—British Rainfall	100	0	0
*Thomson, Professor Sir W.—Underground Temperature	50	0	0
Tait, Professor.—Thermal Conductivity of Iron and other Metals	20	0	0
*Thomson, Professor Sir W.—Tidal Observations	100	0	0
*Glaisher, Mr.—Luminous Meteors.....	30	0	0

Chemistry.

*Matthiessen, Dr.—Chemical Nature of Cast Iron	80	0	0
*Grantham, Mr.—Treatment and Utilization of Sewage.....	50	0	0

Geology.

*Lyell, Sir C., Bart.—Kent's-Cavern Exploration	150	0	0
*Duncan, Dr. P. M.—British Fossil Corals	50	0	0
*Woodward, Mr. H.—Sections of Mountain-Limestone Fossils	25	0	0
Symonds, Rev. W. S.—Sedimentary Deposits in the River Onny	3	0	0
*Bryce, Dr.—Earthquakes in Scotland (renewed)	4	0	0
*Huxley, Professor.—Kiltorcan Fossils, Kilkenny	20	0	0
*Mitchell, Mr. W. S.—Leaf-beds of the Lower Bagshot series..	15	0	0

Biology.

*Richardson, Dr.—Physiological Action of Organic Compounds	30	0	0
*Carruthers, Mr.—Fossil Flora of Britain	25	0	0
*Bate, Mr. Spence.—Marine Fauna of Devon and Cornwall ..	20	0	0
*Busk, Mr.—Record of the Progress of Zoology	100	0	0
Stewart, Mr. C.—Structure of the Ear in Fishes	10	0	0
Garraze, Dr.—Heat generated in the Arterialization of Blood	15	0	0

Statistics and Economic Science.

*Bowring, Sir J.—Metrical Committee.....	25	0	0
Total.....	£1572	0	0

* Reappointed.

General Statement of Sums which have been paid on Account of Grants for Scientific Purposes.

	£	s.	d.		£	s.	d.
1834.				Meteorology and Subterranean			
Tide Discussions	20	0	0	Temperature	21	11	0
1835.				Vitrification Experiments.....	9	4	7
Tide Discussions	62	0	0	Cast-Iron Experiments.....	100	0	0
British Fossil Ichthyology	105	0	0	Railway Constants	28	7	2
	£167	0	0	Land and Sea Level	274	1	4
1836.				Steam-vessels' Engines.....	100	0	0
Tide Discussions	163	0	0	Stars in Histoire Céleste	331	18	6
British Fossil Ichthyology	105	0	0	Stars in Lacaille	11	0	0
Thermometric Observations, &c.	50	0	0	Stars in R.A.S. Catalogue.....	6	16	6
Experiments on long-continued				Animal Secretions.....	10	10	0
Heat	17	1	0	Steam-engines in Cornwall	50	0	0
Rain-Gauges.....	9	13	0	Atmospheric Air	16	1	0
Refraction Experiments	15	0	0	Cast and Wrought Iron.....	40	0	0
Lunar Nutation.....	60	0	0	Heat on Organic Bodies	3	0	0
Thermometers	15	6	0	Gases on Solar Spectrum	22	0	0
	£434	14	0	Hourly Meteorological Observa-			
1837.				tions, Inverness and Kingussie	49	7	8
Tide Discussions	284	1	0	Fossil Reptiles	118	2	9
Chemical Constants	24	13	6	Mining Statistics	50	0	0
Lunar Nutation.....	70	0	0		£1595	11	0
Observations on Waves.....	100	12	0	1840.			
Tides at Bristol.....	150	0	0	Bristol Tides	100	0	0
Meteorology and Subterranean				Subterranean Temperature	13	13	6
Temperature	89	5	0	Heart Experiments	18	19	0
Vitrification Experiments.....	150	0	0	Lungs Experiments	8	13	0
Heart Experiments	8	4	6	Tide Discussions	50	0	0
Barometric Observations	30	0	0	Land and Sea Level	6	11	1
Barometers	11	18	6	Stars (Histoire Céleste)	242	10	0
	£918	14	6	Stars (Lacaille)	4	15	0
1838.				Stars (Catalogue)	264	0	0
Tide Discussions	29	0	0	Atmospheric Air	15	15	0
British Fossil Fishes	100	0	0	Water on Iron	10	0	0
Meteorological Observations and				Heat on Organic Bodies	7	0	0
Anemometer (construction)...	100	0	0	Meteorological Observations.....	52	17	6
Cast Iron (Strength of)	60	0	0	Foreign Scientific Memoirs	112	1	6
Animal and Vegetable Substances				Working Population	100	0	0
(Preservation of)	19	1	10	School Statistics.....	50	0	0
Railway Constants	41	12	10	Forms of Vessels	184	7	0
Bristol Tides	50	0	0	Chemical and Electrical Pheno-			
Growth of Plants	75	0	0	mena	40	0	0
Mud in Rivers	3	6	6	Meteorological Observations at			
Education Committee	50	0	0	Plymouth	80	0	0
Heart Experiments	5	3	0	Magnetical Observations	185	13	9
Land and Sea Level	267	8	7		£1546	16	4
Subterranean Temperature	8	6	0	1841.			
Steam-vessels.....	100	0	0	Observations on Waves.....	30	0	0
Meteorological Committee	31	9	5	Meteorology and Subterranean			
Thermometers	16	4	0	Temperature	8	8	0
	£936	12	2	Actinometers.....	10	0	0
1839.				Earthquake Shocks	17	7	0
Fossil Ichthyology.....	110	0	0	Acrid Poisons.....	6	0	0
Meteorological Observations at				Veins and Absorbents	3	0	0
Plymouth	63	10	0	Mud in Rivers	5	0	0
Mechanism of Waves	144	2	0	Marine Zoology.....	15	12	8
Bristol Tides.....	35	18	6	Skeleton Maps	20	0	0
1869.				Mountain Barometers	6	18	6
				Stars (Histoire Céleste).....	185	0	0

	£	s.	d.		£	s.	d.
Stars (Lacaille)	79	5	0	Meteorological Observations, Os-			
Stars (Nomenclature of)	17	19	6	ler's Anemometer at Plymouth	20	0	0
Stars (Catalogue of)	40	0	0	Reduction of Meteorological Ob-			
Water on Iron	50	0	0	servations	30	0	0
Meteorological Observations at				Meteorological Instruments and			
Inverness	20	0	0	Gratuities	39	6	0
Meteorological Observations (re-				Construction of Anemometer at			
duction of)	25	0	0	Inverness	56	12	2
Fossil Reptiles	50	0	0	Magnetic Cooperation	10	8	10
Foreign Memoirs	62	0	0	Meteorological Recorder for Kew			
Railway Sections	38	1	6	Observatory	50	0	0
Forms of Vessels	193	12	0	Action of Gases on Light	18	16	1
Meteorological Observations at				Establishment at Kew Observa-			
Plymouth	55	0	0	tory, Wages, Repairs, Furni-			
Magnetical Observations	61	18	8	ture and Sundries	133	4	7
Fishes of the Old Red Sandstone	100	0	0	Experiments by Captive Balloons	81	8	0
Tides at Leith	50	0	0	Oxidation of the Rails of Railways	20	0	0
Anemometer at Edinburgh	69	1	10	Publication of Report on Fossil			
Tabulating Observations	9	6	8	Reptiles	40	0	0
Races of Men	5	0	0	Coloured Drawings of Railway			
Radiate Animals	2	0	0	Sections	147	18	3
	<u>£1235</u>	<u>10</u>	<u>11</u>	Registration of Earthquake			
1842.				Shocks	30	0	0
Dynamometric Instruments	113	11	2	Report on Zoological Nomencla-			
Anopura Britannicæ	52	12	0	ture	10	0	0
Tides at Bristol	59	8	0	Uncovering Lower Red Sand-			
Gases on Light	30	14	7	stone near Manchester	4	4	6
Chronometers	26	17	6	Vegetative Power of Seeds	5	3	8
Marine Zoology	1	5	0	Marine Testacea (Habits of) ..	10	0	0
British Fossil Mammalia	100	0	0	Marine Zoology	10	0	0
Statistics of Education	20	0	0	Marine Zoology	2	14	11
Marine Steam-vessels' Engines...	28	0	0	Preparation of Report on British			
Stars (Histoire Céleste)	59	0	0	Fossil Mammalia	100	0	0
Stars (Brit. Assoc. Cat. of)	110	0	0	Physiological Operations of Me-			
Railway Sections	161	10	0	dicinal Agents	20	0	0
British Belemnites	50	0	0	Vital Statistics	36	5	8
Fossil Reptiles (publication of				Additional Experiments on the			
Report)	210	0	0	Forms of Vessels	70	0	0
Forms of Vessels	180	0	0	Additional Experiments on the			
Galvanic Experiments on Rocks	5	8	6	Forms of Vessels	100	0	0
Meteorological Experiments at				Reduction of Experiments on the			
Plymouth	68	0	0	Forms of Vessels	100	0	0
Constant Indicator and Dynamo-				Morin's Instrument and Constant			
metric Instruments	90	0	0	Indicator	69	14	10
Force of Wind	10	0	0	Experiments on the Strength of			
Light on Growth of Seeds	8	0	0	Materials	60	0	0
Vital Statistics	50	0	0		<u>£1565</u>	<u>10</u>	<u>2</u>
Vegetative Power of Seeds	8	1	11	1844.			
Questions on Human Race	7	9	0	Meteorological Observations at			
	<u>£1449</u>	<u>17</u>	<u>8</u>	Kingussie and Inverness	12	0	0
1843.				Completing Observations at Ply-			
Revision of the Nomenclature of				mouth	35	0	0
Stars	2	0	0	Magnetic and Meteorological Co-			
Reduction of Stars, British Asso-				operation	25	8	4
ciation Catalogue	25	0	0	Publication of the British Asso-			
Anomalous Tides, Frith of Forth	120	0	0	ciation Catalogue of Stars	35	0	0
Hourly Meteorological Observa-				Observations on Tides on the			
tions at Kingussie and Inverness	77	12	8	East coast of Scotland	100	0	0
Meteorological Observations at				Revision of the Nomenclature of			
Plymouth	55	0	0	Stars	2	9	6
Whewell's Meteorological Ane-				Maintaining the Establishment in			
nometer at Plymouth	10	0	0	Kew Observatory	117	17	8
				Instruments for Kew Observatory	56	7	8

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	£	s.	d.		£	s.	d.
Influence of Light on Plants.....	10	0	0	Computation of the Gaussian			
Subterranean Temperature in				Constants for 1839.....	50	0	0
Ireland	5	0	0	Maintaining the Establishment at			
Coloured Drawings of Railway				Kew Observatory	146	16	7
Sections	15	17	6	Strength of Materials.....	60	0	0
Investigation of Fossil Fishes of				Researches in Asphyxia.....	6	16	2
the Lower Tertiary Strata ...	100	0	0	Examination of Fossil Shells.....	10	0	0
Registering the Shocks of Earth-				Vitality of Seeds	2	15	10
quakes	23	11	10	1844	7	12	3
Structure of Fossil Shells	20	0	0	1845	10	0	0
Radiata and Mollusca of the				Marine Zoology of Cornwall.....	10	0	0
Ægean and Red Seas.....1842	100	0	0	Marine Zoology of Britain	10	0	0
Geographical Distributions of				Exotic Anoplura	25	0	0
Marine Zoology.....1842	10	0	0	Expenses attending Anemometers	11	7	6
Marine Zoology of Devon and				Anemometers' Repairs	2	3	6
Cornwall	10	0	0	Atmospheric Waves	3	3	3
Marine Zoology of Corfu	10	0	0	Captive Balloons	8	19	3
Experiments on the Vitality of				Varieties of the Human Race			
Seeds	9	0	3	1844	7	6	3
Experiments on the Vitality of				Statistics of Sickness and Mor-			
Seeds	8	7	3	tality in York	12	0	0
Exotic Anoplura	15	0	0		£685	16	0
Strength of Materials	100	0	0				
Completing Experiments on the				1847.			
Forms of Ships	100	0	0	Computation of the Gaussian			
Inquiries into Asphyxia	10	0	0	Constants for 1839	50	0	0
Investigations on the Internal				Habits of Marine Animals	10	0	0
Constitution of Metals	50	0	0	Physiological Action of Medicines	20	0	0
Constant Indicator and Morin's				Marine Zoology of Cornwall ...	10	0	0
Instrument	10	3	6	Atmospheric Waves	6	9	3
	£981	12	8	Vitality of Seeds	4	7	7
				Maintaining the Establishment at			
1845.				Kew Observatory	107	8	6
Publication of the British Associa-					£208	5	4
tion Catalogue of Stars	351	14	6	1848.			
Meteorological Observations at				Maintaining the Establishment at			
Inverness	30	18	11	Kew Observatory	171	15	11
Magnetic and Meteorological Co-				Atmospheric Waves	3	10	9
operation	16	16	8	Vitality of Seeds	9	15	0
Meteorological Instruments at				Completion of Catalogues of Stars	70	0	0
Edinburgh.....	18	11	9	On Colouring Matters	5	0	0
Reduction of Anemometrical Ob-				On Growth of Plants.....	15	0	0
servations at Plymouth	25	0	0		£275	1	8
Electrical Experiments at Kew				1849.			
Observatory	43	17	8	Electrical Observations at Kew			
Maintaining the Establishment in				Observatory	50	0	0
Kew Observatory	149	15	0	Maintaining Establishment at			
For Kreil's Barometograph	25	0	0	ditto	76	2	5
Gases from Iron Furnaces	50	0	0	Vitality of Seeds	5	8	1
The Actinograph	15	0	0	On Growth of Plants.....	5	0	0
Microscopic Structure of Shells...	20	0	0	Registration of Periodical Phe-			
Exotic Anoplura	10	0	0	nomena	10	0	0
Vitality of Seeds.....1843	2	0	7	Bill on account of Anemometrical			
Vitality of Seeds.....1844	7	0	0	Observations	13	9	0
Marine Zoology of Cornwall.....	10	0	0		£159	19	6
Physiological Action of Medicines	20	0	0	1850.			
Statistics of Sickness and Mor-				Maintaining the Establishment at			
tality in York	20	0	0	Kew Observatory	255	18	0
Earthquake Shocks	15	14	8	Transit of Earthquake Waves ...	50	0	0
	£830	9	9	Periodical Phenomena	15	0	0
1846.				Meteorological Instrument,			
British Association Catalogue of				Azores	25	0	0
Stars	211	15	0		£354	18	0
Fossil Fishes of the London Clay	100	0	0				

	£	s.	d.		£	s.	d.
1851.				Strickland's Ornithological Syn-			
Maintaining the Establishment at				onyms	100	0	0
Kew Observatory (includes part				Dredging and Dredging Forms...	9	13	9
of grant in 1849)	309	2	2	Chemical Action of Light	20	0	0
Theory of Heat	20	1	1	Strength of Iron Plates	10	0	0
Periodical Phenomena of Animals				Registration of Periodical Pheno-			
and Plants	5	0	0	mena	10	0	0
Vitality of Seeds	5	6	4	Propagation of Salmon	10	0	0
Influence of Solar Radiation	30	0	0		£344	13	5
Ethnological Inquiries	12	0	0	1857.			
Researches on Annelida	10	0	0	Maintaining the Establishment at			
	£391	9	7	Kew Observatory	350	0	0
1852.				Earthquake Wave Experiments...	40	0	0
Maintaining the Establishment at				Dredging near Belfast	10	0	0
Kew Observatory (including				Dredging on the West Coast of			
balance of grant for 1850) ...	233	17	8	Scotland	10	0	0
Experiments on the Conduction				Investigations into the Mollusca			
of Heat	5	2	9	of California	10	0	0
Influence of Solar Radiations ...	20	0	0	Experiments on Flax	5	0	0
Geological Map of Ireland	15	0	0	Natural History of Madagascar ..	20	0	0
Researches on the British Anne-				Researches on British Annelida ..	25	0	0
lida	10	0	0	Report on Natural Products im-			
Vitality of Seeds	10	6	2	ported into Liverpool	10	0	0
Strength of Boiler Plates	10	0	0	Artificial Propagation of Salmon ..	10	0	0
	£301	6	7	Temperature of Mines	7	8	0
1853.				Thermometers for Subterranean			
Maintaining the Establishment at				Observations	5	7	4
Kew Observatory	165	0	0	Life Boats	5	0	0
Experiments on the Influence of					£667	15	4
Solar Radiation	15	0	0	1858.			
Researches on the British Anne-				Maintaining the Establishment at			
lida	10	0	0	Kew Observatory	500	0	0
Dredging on the East Coast of				Earthquake Wave Experiments...	20	0	0
Scotland	10	0	0	Dredging on the West Coast of			
Ethnological Queries	5	0	0	Scotland	10	0	0
	£205	0	0	Dredging near Dublin	5	0	0
1854.				Vitality of Seeds	5	5	0
Maintaining the Establishment at				Dredging near Belfast	15	13	2
Kew Observatory (including				Report on the British Annelida ..	25	0	0
balance of former grant)	350	15	4	Experiments on the production			
Investigations on Flax	11	0	0	of Heat by Motion in Fluids ...	20	0	0
Effects of Temperature on				Report on the Natural Products			
Wrought Iron	10	0	0	imported into Scotland	10	0	0
Registration of Periodical Pheno-					£615	15	2
mena	10	0	0	1859.			
British Annelida	10	0	0	Maintaining the Establishment at			
Vitality of Seeds	5	2	3	Kew Observatory	500	0	0
Conduction of Heat	4	2	0	Dredging near Dublin	15	0	0
	£380	19	7	Osteology of Bird	50	0	0
1855.				Irish Tomcats	5	0	0
Maintaining the Establishment at				Manner Experiments	20	0	0
Kew Observatory	425	0	0	British Medicine	5	0	0
Earthquake Movements	10	0	0	Dredging Committee	5	0	0
Physical Aspect of the Moon	11	8	5	Steam-vessels' Performance	5	0	0
Vitality of Seeds	10	7	11	Marine Fauna of South and West			
Map of the World	15	0	0	of Ireland	10	0	0
Ethnological Queries	5	0	0	Photographic Chemistry	10	0	0
Dredging near Belfast	4	0	0	Lanarkshire Fossils	20	0	1
	£480	16	4	Balloon Ascents	34	11	0
1856.					£644	11	1
Maintaining the Establishment at				1860.			
Kew Observatory:—				Maintaining the Establishment at			
1854.....£ 75	0	0	0	of Kew Observatory	500	0	0
1855.....£500	0	0	0	Dredging near Belfast	10	0	0
	575	0	0	Dredging in Dublin Bay	15	0	0

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	£	s.	d.
Inquiry into the Performance of Steam-vessels	124	0	0
Explorations in the Yellow Sandstone of Dura Den	20	0	0
Chemico-mechanical Analysis of Rocks and Minerals	25	0	0
Researches on the Growth of Plants	10	0	0
Researches on the Solubility of Salts	30	0	0
Researches on the Constituents of Manures	25	0	0
Balance of Captive Balloon Accounts	1	13	6
	£1241	7	0

1861.

Maintaining the Establishment of Kew Observatory	500	0	0
Earthquake Experiments	25	0	0
Dredging North and East Coasts of Scotland	23	0	0
Dredging Committee:—			
1860	£50	0	0
1861	£22	0	0
Excavations at Dura Den	20	0	0
Solubility of Salts	20	0	0
Steam-vessel Performance	150	0	0
Fossils of Lesmahago	15	0	0
Explorations at Uriconium	20	0	0
Chemical Alloys	20	0	0
Classified Index to the Transactions	100	0	0
Dredging in the Mersey and Dee Dip Circle	30	0	0
Photoheliographic Observations	50	0	0
Prison Diet	20	0	0
Gauging of Water	10	0	0
Alpine Ascents	6	5	1
Constituents of Manures	25	0	0
	£1111	5	10

1862.

Maintaining the Establishment of Kew Observatory	500	0	0
Patent Laws	21	6	0
Mollusca of N.-W. America	10	0	0
Natural History by Mercantile Marine	5	0	0
Tidal Observations	25	0	0
Photoheliometer at Kew	40	0	0
Photographic Pictures of the Sun Rocks of Donegal	25	0	0
Dredging Durham and Northumberland	25	0	0
Connexion of Storms	20	0	0
Dredging North-East Coast of Scotland	6	9	6
Ravages of Teredo	3	11	0
Standards of Electrical Resistance	50	0	0
Railway Accidents	10	0	0
Balloon Committee	200	0	0
Dredging Dublin Bay	10	0	0
Dredging the Mersey	5	0	0
Prison Diet	20	0	0
Gauging of Water	12	10	0

	£	s.	d.
Steamships' Performance	150	0	0
Thermo-Electric Currents	5	0	0
	£1293	16	6

1863.

Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee deficiency	70	0	0
Balloon Ascents (other expenses)	25	0	0
Entozoa	25	0	0
Coal Fossils	20	0	0
Herrings	20	0	0
Granites of Donegal	5	0	0
Prison Diet	20	0	0
Vertical Atmospheric Movements	13	0	0
Dredging Shetland	50	0	0
Dredging North-east coast of Scotland	25	0	0
Dredging Northumberland and Durham	17	3	10
Dredging Committee superintendence	10	0	0
Steamship Performance	100	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Volcanic Temperature	100	0	0
Bromide of Ammonium	8	0	0
Electrical Standards	100	0	0
— Construction and distribution	40	0	0
Luminous Meteors	17	0	0
Kew Additional Buildings for Photoheliograph	100	0	0
Thermo-Electricity	15	0	0
Analysis of Rocks	8	0	0
Hydroids	10	0	0
	£1608	3	10

1864.

Maintaining the Establishment of Kew Observatory	600	0	0
Coal Fossils	20	0	0
Vertical Atmospheric Movements	20	0	0
Dredging Shetland	75	0	0
Dredging Northumberland	25	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Standards of Electric Resistance	100	0	0
Analysis of Rocks	10	0	0
Hydroids	10	0	0
Askham's Gift	50	0	0
Nitrite of Amyle	10	0	0
Nomenclature Committee	5	0	0
Ram-Gauges	19	15	8
Cast-Iron Investigation	20	0	0
Tidal Observations in the Humber	50	0	0
Spectral Rays	45	0	0
Luminous Meteors	20	0	0
	£1289	15	8

1865.

Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee	100	0	0
Hydroids	13	0	0

	£	s.	d.
Rain-Gauges	30	0	0
Tidal Observations in the Humber	6	8	0
Hexylic Compounds	20	0	0
Amyl Compounds	20	0	0
Irish Flora	25	0	0
American Mollusca	3	9	0
Organic Acids	20	0	0
Lingula Flaga Excavation	10	0	0
Eurypterus	50	0	0
Electrical Standards	100	0	0
Malta Caves Researches	30	0	0
Oyster Breeding	25	0	0
Gibraltar Caves Researches	150	0	0
Kent's Hole Excavations	100	0	0
Moon's Surface Observations	35	0	0
Marine Fauna	25	0	0
Dredging Aberdeenshire	25	0	0
Dredging Channel Islands	50	0	0
Zoological Nomenclature	5	0	0
Resistance of Floating Bodies in Water	100	0	0
Bath Waters Analysis	8	10	0
Luminous Meteors	40	0	0

£1591 7 10

1866.

Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	64	13	1
Balloon Committee	50	0	0
Metrical Committee	50	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	16	0	0
Alum Bay Fossil Leaf-Bed	15	0	0
Luminous Meteors	50	0	0
Lingula Flaga Excavation	20	0	0
Chemical Constitution of Cast Iron	50	0	0
Amyl Compounds	25	0	0
Electrical Standards	100	0	0
Malta Caves Exploration	70	0	0
Kent's Hole Exploration	200	0	0
Marine Fauna, &c., Devon and Cornwall	25	0	0
Dredging Aberdeenshire Coast	25	0	0
Dredging Hebrides Coast	50	0	0
Dredging the Mersey	5	0	0
Resistance of Floating Bodies in Water	50	0	0
Polycyanides of Organic Radicals	20	0	0
Rigor Mortis	10	0	0
Irish Annelida	15	0	0
Catalogue of Crania	50	0	0
Dieline Birds of Mascarene Islands	50	0	0
Typical Crania Researches	30	0	0
Palestine Exploration Fund	100	0	0

£1750 13 4

1867.

Maintaining the Establishment of Kew Observatory	600	0	0
Meteorological Instruments, Palestine	50	0	0
Lunar Committee	120	0	0

Metrical Committee	50	0	0
Kent's Hole Explorations	100	0	0
Palestine Explorations	50	0	0
Insect Fauna, Palestine	50	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	25	0	0
Alum Bay Fossil Leaf-Bed	25	0	0
Luminous Meteors	50	0	0
Bournemouth, &c., Leaf-Bed	30	0	0
Dredging, Shetland	75	0	0
Steamship Reports Condensation	100	0	0
Electrical Standards	100	0	0
Ethyle and Methylene series	25	0	0
Fossil Crustacea	25	0	0
Sound under Water	24	1	0
North Greenland Fauna	75	0	0
Do. Plant Beds	100	0	0
Iron and Steel Manufacture	25	0	0
Patent Laws	50	0	0
	£11730	4	0

1868.

Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	120	0	0
Metrical Committee	50	0	0
Zoological Record	100	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	100	0	0
British Rainfall	50	0	0
Luminous Meteors	50	0	0
Organic Acids	60	0	0
Fossil Crustacea	25	0	0
Methylene	25	0	0
Mercury and Bile	25	0	0
Organic remains in Limestone Rocks	25	0	0
Scottish Earthquakes	20	0	0
Fauna, Devon and Cornwall	30	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-beds	50	0	0
Greenland Explorations	100	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Spectroscopic investigations of Animal Substances	5	0	0
Secondary Peptides, &c., ...	50	0	0
British Marine Invertebrate Fauna	100	0	0
	£1910	0	0

1869.

Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	50	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	50	0	0
Thermal Conductivity of Iron, &c., ...	30	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	30	0	0

	£	s.	d.		£	s.	d.
Chemical Constitution of Cast				Underground Temperature	30	0	0
Iron	80	0	0	Spectroscopic Investigations of			
Iron and Steel Manufacture ...	100	0	0	Animal Substances	5	0	0
Methyl Series	30	0	0	Organic Acids	12	0	0
Organic remains in Limestone				Kiltorcan Fossils	20	0	0
Rocks.....	10	0	0	Chemical Constitution and Phy-			
Earthquakes in Scotland.....	10	0	0	siological Action Relations ...	15	0	0
British Fossil Corals	50	0	0	Mountain Limestone Fossils	25	0	0
Bagshot Leaf-beds	30	0	0	Utilization of Sewage	10	0	0
Fossil Flora	25	0	0	Products of Digestion	10	0	0
Tidal Observations	100	0	0				
					<u>£1622</u>	<u>0</u>	<u>0</u>

Extracts from Resolutions of the General Committee.

Committees and individuals, to whom grants of money for scientific purposes have been entrusted, are required to present to each following Meeting of the Association a Report of the progress which has been made; with a statement of the sums which have been expended, and the balance which remains disposable on each grant.

Grants of pecuniary aid for scientific purposes from the funds of the Association expire at the ensuing Meeting, unless it shall appear by a Report that the Recommendations have been acted on, or a continuation of them be ordered by the General Committee.

Members and Committees who are entrusted with sums of money for collecting specimens of Natural History are requested to reserve the specimens so obtained for distribution by authority of the Association.

In each Committee, the Member first named is the person entitled to call on the Treasurer, William Spottiswoode, Esq., 50 Grosvenor Place, London, S.W., for such portion of the sum granted as may from time to time be required.

In grants of money to Committees, the Association does not contemplate the payment of personal expenses to the members.

In all cases where additional grants of money are made for the continuation of Researches at the cost of the Association, the sum named shall be deemed to include, as a part of the amount, the specified balance which may remain unpaid on the former grant for the same object.

General Meetings.

On Wednesday Evening, August 18, at 8 p.m., in the Victoria Hall, Dr. Joseph Dutton Hooker, F.R.S., F.L.S., President, resigned the office of President to Professor G. G. Stokes, D.C.L., F.R.S., who took the Chair, and delivered an Address, for which see page lxxxix.

On Thursday Evening, August 19, at 8 p.m., a Soirée took place in the Albert Memorial Museum.

On Friday Evening, August 20, at 8.30 p.m., in the Victoria Hall, Prof. Phillips, LL.D., F.R.S., F.G.S., delivered a Discourse on "Vesuvius."

On Saturday Evening, August 21, in the Victoria Hall, Prof. W. A. Miller, M.D., F.R.S., delivered a Discourse on "Experimental Illustrations of the modes of determining the Composition of the Sun and Heavenly Bodies by the Spectrum" to the Operative Classes of Exeter.

On Monday Evening, August 23, at 8.30 p.m., in the Victoria Hall, J. Norman Lockyer, F.R.S., delivered a Discourse on the “Physical Constitution of the Stars and Nebulae.”

On Tuesday evening, August 24, at 8 p.m., a Soirée took place in the Albert Memorial Museum.

On Wednesday, August 25, at 2.30 p.m., the concluding General Meeting took place, when the Proceedings of the General Committee, and the Grants of Money for Scientific purposes, were explained to the Members.

The Meeting was then adjourned to Liverpool*.

* The Meeting is appointed to take place on Wednesday, September 14, 1870.

ADDRESS

OF

GEORGE GABRIEL STOKES, M.A., Sec. R.S.,

D.C.L. OXON., LL.D. DUBLIN,

FELLOW OF PEMBROKE COLLEGE, AND LUCASIAN PROFESSOR OF MATHEMATICS IN
THE UNIVERSITY OF CAMBRIDGE,

PRESIDENT.

MY LORDS, LADIES, AND GENTLEMEN,

As this is the first time that the British Association for the Advancement of Science has met in the City of Exeter, and it is probable that many now present have never attended a former Meeting, I hope the older members of the Association will bear with me if I say a few words in explanation of the objects for which the Association was instituted. In the first place, then, it aims at fulfilling an office which is quite distinct from that of the various scientific societies which are established in different parts of the country. These, for the most part, have for their leading object to make the voluntary labours of isolated workers in science available to the scientific world generally by receiving, discussing, and publishing the results which they may have obtained. The British Association, on the other hand, aims at giving *a more systematic direction* to scientific inquiry, and that in various ways.

In a rapidly progressing branch of science it is by no means easy to become acquainted with its actual state. The workers in it are scattered throughout the civilized world, and their results are published in a variety of Transactions and scientific periodicals, mixed with other scientific matter. To make oneself, without assistance, well acquainted with what has been done, it is requisite to have access to an extensive library, to be able to read with facility several modern languages, and to have leisure to hunt through the tables of contents, or at least the indices, of a number of serial works. Without such knowledge, there is always the risk that a scientific man may spend his strength in doing over again what has been done already; whereas with better direction the same expenditure of time and labour might have resulted in some substantial addition to our knowledge. With a view to meet this difficulty, the British Association has requested individuals who were more specially conversant with particular departments of science, to draw up reports on the present state of our knowledge in, or on the recent progress of, special branches; and the influence of the Association as a public body has been found sufficient to induce a number of scientific men to undertake the great labour of preparing such reports.

By thus ascertaining thoroughly what we already had, what we still wanted was made more clear; and, indeed, it was one special object of the reports I have mentioned to point out what were the more prominent desi-

derata in the various subjects to which they related. The Association was thus the better enabled to fulfil another of its functions, that of organizing means for the prosecution of researches which require cooperation. When the want is within the compass of what can be accomplished by individuals, the demand may be left to create the supply; but it often happens that a research can hardly be carried out without cooperation. It may, for instance, require a combination of the most profound theoretical knowledge with the greatest experimental skill, or an extensive knowledge of very dissimilar branches of science; or, again, the work to be done, though all of one kind, may be of such an extent as to be beyond the power of any one man. In such cases the limited power of the individual can only be supplemented by the principle of cooperation; and accordingly it becomes an important part of the business of the Association to organize committees for the prosecution of special researches. The researches thus undertaken at the request of the Association are published at length, along with the reports on the progress of science, in the first part of the annual volume.

In close connexion with the last must be mentioned another mode in which the Association contributes to the progress of science. Many researches require not only time and thought, but pecuniary outlay; and it would seem hard that scientific men who give their time and labour gratuitously to carrying out such researches should be further obliged to incur an expenditure which they often can ill afford. The Association accordingly makes grants of money to individuals or Committees for defraying the expenses of such researches. It appears from the report which has just been published that, reckoning up to the year 1867 inclusive, the sum of £29,342 4s. 1d. has been voted by the Association for various scientific objects. Deducting from this the sum of £23 16s. 0d. for the balances of grants not wholly expended, which were returned to the Association, we may say that £29,288 8s. 1d. has been expended in the manner indicated. When we remember that these grants were mostly of small amount, and do not include personal expenses, and that very many of the researches undertaken at the request of the Association do not involve money grants at all, we may form some idea of the amount of scientific activity which has been evoked under the auspices of the Association.

In the address with which the business of the Meeting is opened, it is usual for your President to give some account of the most recent progress of science. The task is by no means an easy one. Few indeed are familiar with science in all its branches; and even to one who was, the selection of topics and the mode of treating them would still present difficulties. I shall not attempt to give an account of the recent progress of science in general, but shall select from those branches with which I am more familiar some examples of recent progress which may, I hope, prove to be of pretty general interest. And even in this I feel that I shall have to crave your indulgence, for it is hard to be intelligible to some without being wearisome to others.

Among the various branches of physical science, astronomy occupies in many respects a foremost rank. The movements of the heavenly bodies have occupied the attention and excited the interest of mankind from the earliest ages, and accordingly the first rudiments of the science are lost in the depths of antiquity. The grandeur of the subjects of contemplation which it presents to us have won for it especial favour, and its importance in relation to navigation has caused it to be supported by national resources. Newton's great discovery of universal gravitation raised it from the rank of a science of observation to that of one admitting of the most exact mathematical des-

duction; and the investigation of the consequences of this law, and the explanation thereby of the lunar and planetary disturbances, have afforded a field for the exercise of the highest mathematical powers on the part of Newton and his successors. Gradually the apparent anomalies, as they might have been deemed, in the motions of the heavenly bodies were shown to be necessary consequences of the one fundamental law; and at last, as the result of calculations of enormous labour, tables were constructed enabling the places of those bodies at any given time to be determined years beforehand with astonishing precision. A still more striking step was taken. When it had been shown by careful calculation that the apparent motion of the remotest of the planets then known to belong to our system could not be wholly explained on the theory of gravitation, by taking account of the disturbing powers of the other known planets, Adams in our own country, and Le Verrier in France, boldly reversed the problem, and instead of determining the disturbing effect of a known planet, set themselves to inquire what must be the mass and orbit of an unknown planet which shall be capable of producing by its disturbing force the unexplained deviations in the position of Uranus from its calculated place. The result of this inquiry is too well known to require notice.

After these brilliant achievements, some may perhaps have been tempted to imagine that the field of astronomical research must have been well-nigh exhausted. Small perturbations, hitherto overlooked, might be determined, and astronomical tables thereby rendered still more exact. New asteroids might be discovered by the telescope. More accurate values of the constants with which we have to deal might be obtained. But no essential novelty of principle was to be looked for in the department of astronomy; for such we must go to younger and less mature branches of science.

Researches which have been carried on within the last few years, even the progress which has been made within the last twelve months, shows how short-sighted such an anticipation would have been; what an unexpected flood of light may sometimes be thrown over one science by its union with another; how conducive accordingly to the advancement of science may be an Association like the present, in which not only are the workers at special sciences brought together in the Sectional Meetings, but in the General Meetings of the Association, and in the social intercourse, which, though of an informal character, is no unimportant part of our proceedings; the cultivators of different branches of science are brought together, and have an opportunity of enlarging their minds by contact with the minds of others, who have been used to trains of thought of a very different character from their own.

The science of astronomy is indebted to that of optics for the principles which regulate the construction of those optical instruments which are so essential to the astronomer. It repaid its debt by furnishing to optics a result which it is important we should keep in view in considering the nature of light. It is to astronomy that we are indebted for the first proof we obtained of the finite velocity of light, and for the first numerical determination of that enormous velocity. Astronomy, again, led, forty-four years later, to a second determination of that velocity in the remarkable phenomenon of aberration discovered by Bradley, a phenomenon presenting special points of interest in relation to the nature of light, and which has given rise to some discussion, extending even to the present day, so that the Astronomer Royal has not deemed it unworthy of investigation, laborious as he foresees the trial is likely to prove, to determine the constant of aberration by means of a telescope having its tube filled with water.

If in respect of these phenomena optics received much aid from astronomy, the latter science has been indebted to the former for information which could not otherwise have been obtained. The motions and the masses of the heavenly bodies are revealed to us more or less fully by astronomical observations; but we could not thus become acquainted with the chemical nature of these distant objects. Yet, by the application of the spectroscope to the scrutiny of the heavenly bodies, evidence has been obtained of the existence therein of various elements known to us by the chemical examination of the materials of which our own earth is composed; and not only so, but light is thrown on the state in which matter is there existing, which, in the case of nebulae especially, led to the formation of new ideas respecting their constitution, and the rectification of astronomical speculations previously entertained. I shall not, however, dwell further on this part of the subject, which is now of some years' standing, and has been mentioned by more than one of your former Presidents, but will pass on to newer researches in the same direction.

We are accustomed to apply to the stars the epithet *fixed*. Night after night they are seen to have the same relative arrangement; and when their places are determined by careful measurement, and certain small corrections due to known causes are applied to the immediate results of observation, they are found to have the same relative distances. But when instead of days the observations extend over months or years, it is found that the fixity is not quite absolute. Defining as fixity invariability of position as estimated with reference to the stars as a whole, and comparing the position of any individual star with those of the stars in its neighbourhood, we find that some of the stars exhibit "proper motions," show, that is, a progressive change of angular position as seen from the earth, or rather as they would be seen from the sun, which we may take for the mean annual place of the earth. This indicates linear motion in a direction transverse to the line joining the sun with the star. But since our sun is merely a star, a line drawn from the star exhibiting proper motion to our sun is, as regards the former, merely a line drawn to a star taken at random, and therefore there is no reason why the star's motion should be, except accidentally, in a direction perpendicular to the line joining the star with our sun. We must conclude that the stars, including our own sun, or some of them at least, are moving in various directions in space, and that it is merely the transversal component of the whole motion, or rather of the motion relatively to our sun, that is revealed to us by a change in the star's apparent place.

How then shall we determine whether any particular star is approaching to or receding from our sun? It is clear that astronomy alone is powerless to aid us here, since such a motion would be unaccompanied by change of angular position. Here the science of optics comes to our aid in a remarkable manner.

The pitch of a musical note depends, as we know, on the number of vibrations which reach the ear in a given time, such as a second. Suppose, now, that a body, such as a bell, which is vibrating a given number of times per second, is at the same time moving from the observer, the air being calm. Since the successive pulses of sound travel all with the velocity of sound, but diverge from different centres, namely, the successive points in the bell's path at which the bell was when those pulses were first excited, it is evident that the sound-waves will be somewhat more spread out on the side from which the bell is moving, and more crowded together on the side towards which it is moving, than if the bell had been at rest.

Consequently the number of vibrations per second which reach the ear of an observer situated in the former of these directions will be somewhat smaller, and the number which reach an observer situated in the opposite direction somewhat greater, than if the bell had been at rest. Hence to the former the pitch will be somewhat lower, and to the latter somewhat higher, than the natural pitch of the bell. And the same thing will happen if the observer be in motion instead of the bell, or if both be in motion; in fact, the effect depends only on the *relative* motion of the observer and the bell in the direction of a line joining the two,—in other words, on the velocity of recession or approach of the observer and the bell. The effect may be perceived in standing by a railway when a train in which the steam-whistle is sounding passes by at full speed, or better still, if the observer be seated in a train which is simultaneously moving in the opposite direction.

The present state of optical science is such as to furnish us with evidence, of a force which is perfectly overwhelming, that light consists of a tremor or vibratory movement propagated in an elastic medium filling the planetary and stellar spaces, a medium which thus fulfils for light an office similar to that of air for sound. In this theory, to difference of periodic time corresponds difference of refrangibility. Suppose that we were in possession of a source of light capable, like the bell in the analogous case of sound, of exciting in the æther supposed at rest vibrations of a definite period, corresponding, therefore, to light of a definite refrangibility. Then, just as in the case of sound, if the source of light and the observer were receding from or approaching to each other with a velocity which was not insensibly small compared with the velocity of light, an appreciable lowering or elevation of refrangibility would be produced, which would be capable of detection by means of a spectroscope of high dispersive power.

The velocity of light is so enormous, about 185,000 miles per second, that it can readily be imagined that any motion which we can experimentally produce in a source of light is as rest in comparison. But the earth in its orbit round the sun moves at the rate of about 18 miles per second; and in the motions of stars approaching to or receding from our sun we might expect to meet with velocities comparable with this. The orbital velocity of the earth is, it is true, only about the one ten-thousandth part of the velocity of light. Still the effect of such a velocity on the refrangibility of light, which admits of being easily calculated, proves not to be so insensibly small as to elude all chance of detection, provided only the observations are conducted with extreme delicacy.

But how shall we find in such distant objects as the stars an analogue of the bell which we have assumed in the illustration drawn from sound? What evidence can we ever obtain, even if an examination of their light should present us with rays of definite refrangibility, of the existence in those remote bodies of ponderable matter vibrating in known periods not identical with those corresponding to the refrangibilities of the definite rays which we observe? The answer to this question will involve a reference, which I will endeavour to make as brief as I can, to the splendid researches of Professor Kirchhoff. The exact coincidence of certain dark lines in the solar spectrum with bright lines in certain artificial sources of light had previously been in one or two instances observed; but it is to Kirchhoff we owe the inference from an extension of Prevost's theory of exchanges, that a glowing medium which emits bright light of any particular refrangibility *necessarily* (at that temperature at least) acts as an absorbing medium, extinguishing light of the same refrangibility. In saying this it is but just to mention that in relation

to radiant heat (from whence the transition to light is easy), Kirchhoff was preceded, though unconsciously, by our own countryman Mr. Balfour Stewart. The inference which Kirchhoff drew from Prevost's theory thus extended led him to make a careful comparison of the places of the dark lines of the solar spectrum with those of bright lines produced by the incandescent gas or vapour of known elements; and the coincidences were in many cases so remarkable as to establish almost to a certainty the existence of several of the known elements in the solar atmosphere, producing by their absorbing action the dark lines coinciding with the bright lines observed. Among other elements may be mentioned in particular hydrogen, the spectrum of which, when the gas is traversed by an electric discharge, shows a bright line or band exactly coinciding with the dark line C, and another with the line F.

Now Mr. Huggins found that several of the stars show in their spectra dark lines coinciding in position with C and F; and what strengthens the belief that this coincidence, or apparent coincidence, is not merely fortuitous, but is due to a common cause, is that the two lines are found associated together, both present or both absent. And Kirchhoff's theory suggests that the common cause is the existence of hydrogen in the atmospheres of the sun and certain stars, and its exercise of an absorbing action on the light emitted from beneath.

Now by careful and repeated observations with a telescope furnished with a spectroscope of high dispersive power, Mr. Huggins found that the F line, the one selected for observation, in the spectrum of Sirius did not exactly coincide with the corresponding bright line of a hydrogen spark, which latter agrees in position with the solar F, but was a *little* less refrangible, while preserving the same general appearance. What conclusion, then, are we to draw from the result? Surely it would be most unreasonable to attribute the dark lines in the spectra of the sun and of Sirius to distinct causes, and to regard their almost exact coincidence as purely fortuitous, when we have in proper motion a *vera causa* to account for a minute difference. And if, as Kirchhoff's labours render almost certain, the dark solar line depends on the existence of hydrogen in the atmosphere of our sun, we are led to infer that that element, with which the chemist working in his laboratory is so familiar, exists and is subject to the same physical laws in that distant star, so distant, that, judging by the most probable value of its annual parallax, light which would go seven times round our earth in one second would take fourteen years to travel from the star. What a grand conception of the unity of plan pervading the universe do such conclusions present to our minds!

Assuming, then, that the small difference of refrangibility observed between the solar F and that of Sirius is due to proper motion, Mr. Huggins concludes from his measures of the minute difference of position that at the time of the observation Sirius was receding from the earth at the rate of 41.4 miles per second. A part of this was due to the motion of the earth in its orbit; and on deducting the orbital velocity of the earth, resolved in the direction of a line drawn from the star, there remained 29.4 miles per second as the velocity with which Sirius and our sun are mutually receding from each other. Considering the minuteness of the quantity on which the result depends, it is satisfactory to find that Mr. Huggins's results as to the motion of Sirius have been confirmed by the observations of Father Secchi made at Rome with a different instrument.

The determination of radial proper motion in this way is still in its infancy. It is worthy of note that, unlike the detection of transversal proper motion

by change of angular position, it is equally applicable to stars at all distances, provided they are bright enough to render the observations possible. It is conceivable that the results of these observations may one day lead to a determination of the motion of the solar system in space, which is more trustworthy than that which has been deduced from changes of position, as being founded on a broader induction, and not confined to conclusions derived from the stars in our neighbourhood. Should even the solar system and the nearer stars be drifting along, as Sir John Herschel suggests, with an approximately common motion, like motes in a sunbeam, it is conceivable that the circumstance might thus be capable of detection. To what wide speculations are we led as to the possible progress of our knowledge when we put together what has been accomplished in different branches of science!

I turn now to another recent application of spectral analysis. The phenomenon of a total solar eclipse is described by those who have seen it as one of the most imposing that can be witnessed. The rarity of its occurrence and the shortness of its duration afford, however, opportunity for only a hasty study of the phenomena which may then present themselves. Among these, one of the most remarkable, seen indeed before, but first brought prominently into notice by the observers who watched the eclipse of July 7, 1842, consists in a series of mountain-like or cloud-like luminous objects seen outside the dark disk of the moon. These have been seen in subsequent total eclipses, and more specially studied, by means of photography, by Mr. Warren De La Rue in the eclipse of June 18, 1860. The result of the various observations, and especially the study, which could be made at leisure, of the photographs obtained by Mr. De La Rue, proved conclusively that these appendages belong to the sun, not to the moon. The photographs proved further their light to be remarkable for actinic power. Since that time the method of spectral analysis has been elaborated; and it seemed likely that additional information bearing on the nature of these objects might be obtained by the application of the spectroscope. Accordingly various expeditions were equipped for the purpose of observing the total solar eclipse which was to happen on August 17, 1868. In our own country an equatorially mounted telescope provided with a spectroscope was procured for the purpose by the Royal Society, which was entrusted to Lieut. (now Captain) Herschel, who was going out to India, one of the countries crossed by the line of the central shadow. Another expedition was organized by the Royal Astronomical Society, under the auspices of Major Temant, who was foremost in pressing on the attention of scientific men the importance of availing themselves of the opportunity.

Shortly before the conclusion of the Meeting of the Association at Norwich last year, the first results of the observations were made known to the Meeting through the agency of the electric telegraph. In a telegram sent by M. Janssen to the President of the Royal Society, it was announced that the spectrum of the prominences was very remarkable, showing bright lines, while that of the corona showed none. Brief as the message necessarily was, one point was settled. The prominences could not be clouds in the strict sense of the term, shining either by virtue of their own heat, or by light reflected from below. They must consist of incandescent matter in the *gaseous* form. It appeared from the more detailed accounts received by post from the various observers, and put together at leisure, that except in the immediate neighbourhood of the sun the light of the prominences consisted mainly of three bright lines, of which two coincided, or nearly so, with C and F, and the intermediate one nearly, but, as subsequent researches

showed, not exactly, with D. The bright lines coinciding with C and F indicate the presence of glowing hydrogen.

This is precious information to have gathered during the brief interval of the total phase, and required on the part of the observers self-denial in withdrawing the eye from the imposing spectacle of the surrounding scenery, and coolness in proceeding steadily with some definite part of the inquiry, when so many questions crowded for solution, and the fruits of months of preparation were to be reaped in three or four minutes or lost altogether; especially when, as too often happened, the observations were provokingly interrupted by flying clouds.

But valuable as these observations were, it is obvious that we should have had long to wait before we could have become acquainted with the usual behaviour of these objects, and their possible relation to changes which may be going on at the surface of the sun, if we had been dependent on the rare and brief phenomenon of a total solar eclipse for gathering information respecting them. But how, the question might be asked, shall we ever be able so to subdue the overpowering glare of our great luminary, and the dazzling illumination which it produces in our atmosphere when we look nearly in its direction, as to perceive objects which are comparatively so faint? Here again the science of optics comes in aid of astronomy.

When a line of light, such as a narrow slit held in front of a luminous object, is viewed through a prism, the light is ordinarily spread out into a coloured band, the length of which may be increased at pleasure by substituting two or more prisms for the single prism. As the total quantity of light is not thereby increased, it is obvious that the intensity of the light of the coloured band will go on decreasing as the length increases. Such is the case with ordinary sources of light, like the flame of a candle or the sky, which give a continuous spectrum, or one generally continuous, though interrupted by dark bands. But if the light from the source be homogeneous, consisting, that is, of light of one degree of refrangibility only, the image of the slit will be merely deviated by the prisms, not widened out into a band, and not consequently reduced in intensity by the dispersion. And if the source of light emit light of both kinds, it will be easily understood that the images of the slit corresponding to light of any definite refrangibilities which the mixture may contain will stand out, by their superior intensity, on the weaker ground of the continuous spectrum.

Preparations for observations of the kind had long been in progress in the hands of our countryman Mr. Lockyer. His first attempts were unsuccessful; but undismayed by failure, he ordered the construction of a new spectroscope of superior power, in which he was aided by a grant from the sum placed annually by Parliament at the disposal of the Royal Society for scientific purposes. The execution of this instrument was delayed by what proved to be the last illness of the eminent optician to whom it had been in the first instance entrusted, the late Mr. Cooke; but when at last the instrument was placed in his hands, Mr. Lockyer was not long in discovering the object of his two years' search. On the 20th of October last year, in examining the space immediately surrounding the edge of the solar disk, he obtained evidence, by the occurrence of a bright line in the spectrum, that his slit was on the image of one of those prominences, the nature of which had so long been an enigma. It further appeared from an observation made on November 5 (as indeed might be expected from the photographs of Mr. De La Rue, and the descriptions of those who had observed total solar eclipses) that the prominences were merely elevated portions of an extensive luminous stratum of the same general char-

rafter, which, now that the necessity of the interposition of the moon was dispensed with, could be traced completely round the sun. Notices of this discovery were received from the author by the Royal Society on October 21 and November 3, and the former was almost immediately published in No. 105 of the Proceedings. These were shortly afterwards followed by a fuller paper on the same subject.

Meanwhile the same thing had been independently observed in another part of the world. After having observed the remarkable spectrum of the prominences during the total eclipse, it occurred to M. Janssen that the same method might allow the prominences to be detected at any time; and on trial he succeeded in detecting them the very day after the eclipse. The results of his observations were sent by post, and were received shortly after the account of Mr. Lockyer's discovery had been communicated by Mr. De La Rue to the French Academy.

In the way hitherto described a prominence is not seen as a whole, but the observer knows when its image is intercepted by the slit; and by varying a little the position of the slit a series of sections of the prominence are obtained, by putting which together the form of the prominence is deduced. Shortly after Mr. Lockyer's communication of his discovery, Mr. Huggins, who had been independently engaged in the attempt to render the prominences visible by the aid of the spectroscope, succeeded in seeing a prominence as a whole by somewhat widening the slit, and using a red glass to diminish the glare of the light admitted by the slit, the prominence being seen by means of the C line in the red. Mr. Lockyer had a design for seeing the prominences as a whole by giving the slit a rapid motion of small extent, but this proved to be superfluous, and they are now habitually seen with their actual forms. Nor is our power of observing them restricted to those which are so situated that they are seen by projection outside the sun's limb; such is the power of the spectroscopic method of observation that it has enabled Mr. Lockyer and others to observe them right on the disk of the sun, an important step for connecting them with other solar phenomena.

One of the most striking results of the habitual study of these prominences is the evidence they afford of the stupendous changes which are going on in the central body of our system. Prominences the heights of which are to be measured by thousands and tens of thousands of miles, appear and disappear in the course of some minutes. And a study of certain minute changes of position in the bright line F, which receive a simple and natural explanation by referring them to proper motion in the glowing gas by which that line is produced, and which we see no other way of accounting for, have led Mr. Lockyer to conclude that the gas in question is sometimes travelling with velocities comparable with that of the earth in its orbit. Moreover these exhibitions of intense action are frequently found to be intimately connected with the spots, and can hardly fail to throw light on the disputed question of their formation. Nor are chemical composition and proper motion the only physical conditions of the gas which are accessible to spectral analysis. By comparing the breadth of the bright bands (for though narrow they are not mere lines) seen in the prominences with those observed in the spectrum of hydrogen rendered incandescent under different physical conditions, Dr. Frankland and Mr. Lockyer have deduced conclusions respecting the pressure to which the gas is subject in the neighbourhood of the sun. I am happy to say that Mr. Lockyer has consented to deliver a discourse during our Meeting, in which the whole subject will doubtless be fully explained.

I have dwelt perhaps too long on this topic, and I cannot help fearing that

I may have been tedious to the many scientific men to whom the subject is already perfectly familiar. Yet the contemplations which it opens out to us are so exalted, and the proof which it affords of what can be accomplished by the union of different branches of science is so striking, that I hope I may be pardoned for occupying your time. I cannot, however, leave the subject of Astronomy without congratulating the Association on the accomplishment of an object which originated with it, and in the promotion of which it formerly took an active part. It was at the Meeting of the Association at Birmingham in 1849, under the presidency of the Rev. Dr. Robinson, that a resolution was passed for making an application to Her Majesty's Government to establish a reflector of not less than three feet aperture at the Cape of Good Hope, and to make such additions to the staff of that observatory as might be necessary for its effectual working. This resolution met with the hearty concurrence of the President of the Council of the Royal Society, who suggested that the precise locality in the Southern hemisphere where the telescope should be erected had best be left an open question. This modification having been adopted by your Council, the application was presented to Earl Russell, then First Lord of the Treasury, by representatives of both bodies early in 1850. A reply was received from Government to the effect that though they agreed with the Association as to the interest which attached itself to the inquiry, yet there was so much difficulty attending the arrangements that they were not prepared to take any steps without much further enquiry. This reply was considered so far favourable as not to forbid the hope of success if the application were renewed on a suitable opportunity. The subject was again brought before the Association by Colonel (now General Sir Edward) Sabine, in his opening address as President at the Belfast Meeting in 1852. The result was that the matter was again brought before Government by a Committee of the British Association acting in conjunction with a Committee of the Royal Society, by means of an application made to the Earl of Aberdeen. By this time the country was engaged in the Russian war, in consequence of which, it was replied, no funds could then be spared; but a promise was given that when the crisis then impending was past, the matter should be taken up, a promise which the retirement from office and subsequent death of Lord Aberdeen rendered of no avail.

But though failing in its immediate object, the action of the British Association in this matter has not remained fruitless. A few years later the subject was warmly taken up at Melbourne, and after preliminary correspondence between the Board of Visitors of the Melbourne Observatory and the President and Council of the Royal Society, and the appointment by the latter body of a Committee to consider and report on the subject, in April 1864 a proposition was made to the Colonial Legislature for a grant of £5000 for the construction of a telescope, and was acceded to. Not to weary you with details, I will merely say that the telescope has been constructed by Mr. Grubb, of Dublin, and is now erected at Melbourne, and in the hands of Mr. Le Sueur, who has been appointed to use it. It is a reflector of four feet aperture, of the Cassegrain construction, equatorially mounted, and provided with a clock-movement. Before its shipment, it was inspected in Dublin by the Committee appointed by the Royal Society to consider the best mode of carrying out the object for which the vote was made by the Melbourne Legislature; and the Committee speak in the highest terms of its contrivance and execution. We may expect before long to get a first instalment of the results obtained by a scrutiny of the southern heavens with an

instrument far more powerful than any that has hitherto been applied to them—results which will at the same time add to our existing knowledge and redound to the honour of the Colony, by whose liberality this long-cherished object has at last been effected.

As I have mentioned an application to the Government on the part of the Association which was not successful, it is but right to say that such is not generally the result; I will refer to one instance. At the Cambridge Meeting of the Association in 1862, a Committee, consisting of representatives of the Mechanical and Chemical Sections, was appointed for the purpose of investigating the application of gun-cotton to warlike purposes. At the Newcastle Meeting, in the following year, this Committee presented their Report. It was felt that a complete study of the subject demanded appliances which could be obtained only from our military resources, and at the Newcastle Meeting a resolution was passed recommending the appointment of a Royal Commission. This recommendation was adopted, and in 1864 a Commission was appointed, which was requested to report on the application of gun-cotton to Civil as well as to Naval and Military purposes. The Committee gave in their report last year, and that report, together with a more recent return relative to the application of gun-cotton to mining and quarrying operations, has just been printed for the House of Commons.

A substance of such comparatively recent introduction cannot be fairly compared with an explosive in the use of which we have the experience of centuries. Yet, even with our present experience, there are some purposes for which gun-cotton can advantageously replace gunpowder, while its manufacture and storage can be effected with comparative safety, since it is in a wet state during the process of manufacture, and is not at all injured by being kept permanently in water, but merely requires to be dried for use. Even should it be required to store it in the dry state, it is doubtful whether, with the precautions indicated by the chemical investigations of Mr. Abel, any greater risk is incurred than in the case of gunpowder. In the blasting of hard rocks it is found to be highly efficient, while the remarkable results recently obtained by Mr. Abel leave no doubt of its value for explosions such as are frequently required in warfare. General Hay speaks highly of the promise of its value for small arms; but many more experiments are required, especially as a change in the arm and mode of ignition require a change in the construction of the cartridge. In heavy ordnance, the due control of the rapidity of combustion of the substance is a matter of greater difficulty; and, though considerable progress has been made, much remains to be done before the three conditions of safety to the gun, high velocity of projection, and uniformity of result, are satisfactorily combined.

By the kindness of Dr. Carpenter, I am enabled to mention to you the latest results obtained in an expedition which could not have been undertaken without the aid of Government, an aid which was freely given. Last year Dr. Carpenter and Professor Wyville Thomson represented to the President and Council of the Royal Society the great importance to Zoology and Palæontology of obtaining soundings from great depths in the ocean, and suggested to them to use their influence with the Admiralty to induce them to place a gun-boat, or other suitable vessel, at the disposal of those gentlemen and any other naturalists who might be willing to accompany them for the purpose of carrying on a systematic course of deep-sea dredging for a month or six weeks. This application was forwarded to the Admiralty with the warm support of the President and Council, and was readily acceded to. The operations were a good deal impeded by rough weather,

but nevertheless important results were obtained. Dredging was successfully accomplished at a depth of 650 fathoms; and the existence was established of a varied and abundant submarine Fauna, at depths which had generally been supposed to be either azoic, or occupied by animals of a very low type; and the character of the Fauna and of the mud brought up was such as to point to a chalk formation actually going on.

It seemed desirable to carry the soundings to still greater depths, and to examine more fully the changes of temperature which had been met with in the descent. Another application was accordingly made to the Admiralty in the present year, and was no less readily acceded to than the former; and a larger vessel than that used last year is now on her cruise. I am informed by Dr. Carpenter that dredging has been successfully carried down to more than 2400 fathoms (nearly the height of Mont Blanc), and that animal life has been found even at that depth in considerable *variety*, though its *amount* and *kind* are obviously influenced by the reduction of temperature to Arctic coldness. A very careful series of temperature soundings has been taken, showing, on the same spot, a continuous descent of temperature with the depth, at first more rapid, afterwards pretty uniform. Thermometers protected from pressure by a plan devised by Dr. Miller were found to maintain their character at the great depths reached, the difference between them and the best ordinary thermometers used in the same sounding being exactly conformable to the pressure corresponding with each depth, as determined by the experiments previously made in smaller depths. All the observations hitherto made go to confirm the idea of a general interchange of polar and equatorial water, the former occupying the lowest depths, the latter forming a superficial stratum of 700 or 800 fathoms. The analyses of the water brought up indicate a large proportion of carbonic acid in the gases of the deep waters, and a general diffusion of organic matter.

I must turn for a few moments to another application recently made to Government, which has not been successful. The application I have in view was made, not by the British Association or other Scientific Societies in their corporate capacity, but by a body composed of the Presidents of the British Association and of the Royal and other leading Scientific Societies; and its object was, not the promotion of Science directly, but the recognition of preeminent scientific merit. In the history of science few names, indeed, hold so prominent a place as that of Faraday. The perfect novelty of principle and recondite nature of many of his great discoveries are such as to bear the impress of genius of the highest order, and to form an epoch in the advance of science; and while his scientific labours excited the admiration of men of science throughout the world, his singularly genial disposition, and modest unassuming character, won for him the love of those who had the happiness of numbering him among their personal friends. At a meeting of the Presidents of the Scientific Societies [to which I have alluded, it was resolved to erect a statue in memory of Faraday. He was a man of whom England may well be proud, and it was thought that it would be a graceful recognition of his merits if the monument were erected at the public expense. The present Chancellor of the Exchequer, however, did not think it right that the recognition of scientific merit, however eminent, should fall on the taxation of the country, though even in a pecuniary point of view the country has received so much benefit from the labours of scientific men. The carrying out of the resolution being thus left to private exertion, a public meeting, presided over by H.R.H. the Prince of Wales, was held in the Royal Institution, an establishment

which has the honour of being identified with Faraday's scientific career. At this Meeting a Committee was formed to carry out the object, and a subscription list commenced. By permission of the Secretaries of this Association, an office has been opened in the reception-room, where those Members of the Association who may be desirous of taking part in the movement will have every facility afforded them.

In chemistry, I do not believe that any great step has been made within the last year; but perhaps there is no science in which an earnest worker is so sure of being rewarded by making some substantial acquisition to our knowledge, though it may not be of the nature of one of those grand discoveries which from time to time stamp their impress on different branches of science. I may be permitted to refer to one or two discoveries which are exceedingly curious, and some of which may prove of considerable practical importance.

The Turaco or Plantain-eater of the Cape of Good Hope is celebrated for its beautiful plumage. A portion of the wings is of a fine red colour. This red colouring-matter has been investigated by Professor Church, who finds it to contain nearly six per cent. of copper, which cannot be distinguished by the ordinary tests, nor removed from the colouring-matter without destroying it. The colouring-matter is in fact a natural organic compound of which copper is one of the essential constituents. Traces of this metal had previously been found in animals, for example, in oysters, to the cost of those who partook of them. But in these cases the presence of the copper was merely accidental; thus oysters that lived near the mouths of streams which came down from copper-mines assimilated a portion of the copper salt, without apparently its doing them either good or harm. But in the Turaco the existence of the red colouring-matter which belongs to their normal plumage is dependent upon copper, which, obtained in minute quantities with the food, is stored up in this strange manner in the system of the animal. Thus in the very same feather, partly red and partly black, copper was found in abundance in the red parts, but none or only the merest trace in the black.

This example warns us against taking too utilitarian a view of the plan of creation. Here we have a chemical substance elaborated which is perfectly unique in its nature, and contains a metal the salts of which are ordinarily regarded as poisonous to animals; and the sole purpose to which, so far as we know, it is subservient in the animal economy is one of pure decoration. Thus a pair of the birds which were kept in captivity lost their fine red colour in the course of a few days, in consequence of washing in the water which was left them to drink, the red colouring-matter, which is soluble in water, being thus washed out; but except as to the loss of their beauty it does not appear that the birds were the worse for it.

A large part of the calicos which are produced in this country in such enormous quantities are sent out into the market in the printed form. Although other substances are employed, the place which madder occupies among dyestuffs with the calico-printer is compared by Mr. Schuuck to that which iron occupies among metals with the engineer. It appears from the public returns that upwards of 10,000 tons of madder are imported annually into the United Kingdom. The colours which madder yields to mordanted cloth are due to two substances, alizarine and purpurine, derived from the root. Of these, alizarine is deemed the more important, as producing faster colours, and yielding finer violets. In studying the transformations of alizarine under the action of chemical reagents, MM. Grache and Liebermann were led to connect it with anthracene, one of the coal-tar series of bodies,

and to devise a mode of forming it artificially. The discovery is still too recent to allow us to judge of the cost with which it can be obtained by artificial formation, which must decide the question of its commercial employment. But assuming it to be thus obtained at a sufficiently cheap rate, what a remarkable example does the discovery afford of the way in which the philosopher quietly working in his laboratory may obtain results which revolutionize the industry of nations! To the calico-printer indeed it may make no very important difference whether he continues to use madder, or replaces it by the artificial substance; but what a sweeping change is made in the madder-growing interest! What hundreds of acres hitherto employed in madder-cultivation are set free for the production of human food, or of some other substance useful to man! Such changes can hardly be made without temporary inconvenience to those who are interested in the branches of industry affected; but we must not on that account attempt to stay the progress of discovery, which is conducive to the general weal.

Another example of the way in which practical applications unexpectedly turn up when science is pursued for its own sake is afforded by a result recently obtained by Dr. Matthiessen, in his investigation of the constitution of the opium bases. He found that by the action of hydrochloric acid on morphia a new base was produced, which as to composition differed from the former merely by the removal of one equivalent of water. But the physiological action of the new base was utterly different from that of the original one. While morphia is a powerful narcotic, the use of which is apt to be followed by subsequent depression, the new base was found to be free from narcotic properties, but to be a powerful emetic, the action of which was unattended by injurious after-effects. It seems likely to become a valuable remedial agent.

In relation to mechanism, this year is remarkable as being the centenary of the great invention of our countryman James Watt. It was in the year 1769 that he took out his patent involving the invention of separate condensation, which is justly regarded as forming the birth of the steam-engine. Little could even his inventive mind have foreseen the magnitude of the gift he was conferring on mankind in general, and on his own country more particularly. In these days of steamers, power-looms, and railways, it requires no small effort to place ourselves in imagination in the condition we should be in without the steam-engine. It needs no formal celebration to remind Britons of what they owe to Watt. Of him truly it may be said "*si monumentum requiras circumspice.*"

With reference to those branches of science in which we are more or less concerned with the phenomena of life, my own studies give me no right to address you. I regret this the less because my predecessor and my probable successor in the Presidential Chair are both of well-known eminence in this department. But I hope I may be permitted as a physicist, and viewing the question from the physical side, to express to you my views as to the relation which the physical bear to the biological sciences.

No other physical science has been brought to such perfection as mechanics; and in mechanics we have long been familiar with the idea of the perfect generality of its laws, of their applicability to bodies organic as well as inorganic, living as well as dead. Thus in a railway collision when a train is suddenly arrested the passengers are thrown forward, by virtue of the inertia of their bodies, precisely according to the laws which regulate the motion of dead matter. So trite has the idea become that the reference to it may seem

childish ; but from mechanics let us pass on to chemistry, and the case will be found by no means so clear. When chemists ceased to be content with the mere ultimate analysis of organic substances, and set themselves to study their proximate constituents, a great number of definite chemical compounds were obtained which could not be formed artificially. I do not know what may have been the usual opinion at that time among chemists as to their mode of formation. Probably it may have been imagined that chemical affinities were indeed concerned in their formation, but controlled and modified by an assumed vital force. But as the science progressed many of these organic substances were formed artificially, in some cases from other and perfectly distinct organic substances, in other cases actually from their elements. This statement must indeed be accepted with one qualification. It was stated several years ago by M. Pasteur, and I believe the statement still remains true, that no substance the solution of which possesses the property of rotating the plane of polarization of polarized light had been formed artificially from substances not possessing that property. Now several of the natural substances which are deemed to have been produced artificially are active, in the sense of rotating the plane of polarization ; and therefore in these cases the inactive, artificial substances cannot be absolutely identical with the natural ones. But the inactivity of the artificial substance is readily explained on the supposition that the artificial substance bears to the natural, the same relation as racemic acid bears to tartaric,—that it is, so to speak, a mixture of the natural substance with its image in a mirror. And when we remember by what a peculiar and troublesome process M. Pasteur succeeded in separating racemic acid into the right-handed and left-handed tartaric acids, it will be at once understood how easily the fact, if it be a fact, of the existence in the natural substance of a mixture of two substances, one right-handed and the other left-handed, but otherwise identical, may have escaped detection. This is a curious point, to the clearing up of which it is desirable that chemists should direct their attention. Waiving then the difference of activity or inactivity, which, as we have seen, admits of a simple physical explanation, though the correctness of that explanation remains to be investigated, we may say that at the present time a considerable number of what used to be regarded as essentially natural organic substances have been formed in the laboratory. That being the case, it seems most reasonable to suppose that in the plant or animal from which those organic substances were obtained they were formed by the play of ordinary chemical affinity, not necessarily nor probably by the same series of reactions by which they were formed in the laboratory, where a high temperature is commonly employed, but still by chemical reactions of some kind, under the agency in many cases of light, an agency sometimes employed by the chemist in his laboratory. And since the boundary line between the natural substances which have and those which have not been formed artificially is one which, so far as we know, simply depends upon the amount of our knowledge, and is continually changing as new processes are discovered, we are led to extend the same reasoning to the various chemical substances of which organic structures are made up.

But do the laws of chemical affinity, to which, as I have endeavoured to infer, living beings, whether vegetable or animal, are in absolute subjection, together with those of capillary attraction, of diffusion, and so forth, account for the formation of an organic structure, as distinguished from the elaboration of the chemical substances of which it is composed? No more, it seems to me, than the laws of motion account for the union of oxygen and hydrogen to form water

though the ponderable matter so uniting is subject to the laws of motion during the act of union, just as well as before and after. In the various processes of crystallization of precipitation, and so forth, which we witness in dead matter, I cannot see the faintest shadow of an approach to the formation of an organic structure, still less to the wonderful series of changes which are concerned in the growth and perpetuation of even the lowliest plant. Admitting to the full as highly probable, though not completely demonstrated, the applicability to living beings of the laws which have been ascertained with reference to dead matter, I feel constrained at the same time to admit the existence of a mysterious *something* lying beyond,—a *something sui generis*, which I regard, not as balancing and suspending the ordinary physical laws, but as working with them and through them to the attainment of a designed end.

What this *something*, which we call life, may be, is a profound mystery. We know not how many links in the chain of secondary causation may yet remain behind; we know not how few. It would be presumptuous indeed to assume in any case that we had already reached the last link, and to charge with irreverence a fellow-worker who attempted to push his investigations yet one step further back. On the other hand, if a thick darkness enshrouds all beyond, we have no right to assume it to be impossible that we should have reached even the last link of the chain; a stage where further progress is unattainable, and we can only refer the highest law at which we stopped to the fiat of an Almighty Power. To assume the contrary as a matter of necessity, is practically to remove the First Cause of all to an infinite distance from us. The boundary, however, between what is clearly known and what is veiled in impenetrable darkness is not ordinarily thus sharply defined. Between the two there lies a misty region, in which loom the ill-discerned forms of links of the chain which are yet beyond us. But the general principle is not affected thereby. Let us fearlessly trace the dependence of link on link as far as it may be given us to trace it, but let us take heed that in thus studying second causes we forget not the First Cause, nor shut our eyes to the wonderful proofs of design which, in the study of organized beings especially, meet us at every turn.

Truth we know must be self-consistent, nor can one truth contradict another, even though the two may have been arrived at by totally different processes, in the one case, suppose, obtained by sound scientific investigation, in the other case taken on trust from duly authenticated witnesses. Misinterpretations of course there may be on the one side or on the other, causing *apparent* contradictions. Every mathematician knows that in his private work he will occasionally by two different trains of reasoning arrive at discordant conclusions. He is at once aware that there must be a slip somewhere, and sets himself to detect and correct it. When conclusions rest on probable evidence, the reconciling of apparent contradictions is not so simple and certain. It requires the exercise of a calm, unbiassed judgment, capable of looking at both sides of the question; and oftentimes we have long to suspend our decision, and seek for further evidence. None need fear the effect of scientific inquiry carried on in an honest, truth-loving, humble spirit, which makes us no less ready frankly to avow our ignorance of what we cannot explain than to accept conclusions based on sound evidence. The slow but sure path of induction is open to us. Let us frame hypotheses if we will: most useful are they when kept in their proper place, as stimulating inquiry. Let us seek to confront them with observation and experiment, thereby confirming or upsetting them as the result may prove; but let us beware of pla-

cing them prematurely in the rank of ascertained truths, and building further conclusions on them as if they were.

When from the phenomena of life we pass on to those of mind, we enter a region still more profoundly mysterious. We can readily imagine that we *may* here be dealing with phenomena altogether transcending those of mere life, in some such way as those of life transcend, as I have endeavoured to infer, those of chemistry and molecular attractions, or as the laws of chemical affinity in their turn transcend those of mere mechanics. Science can be expected to do but little to aid us here, since the instrument of research is itself the object of investigation. It can but enlighten us as to the depth of our ignorance, and lead us to look to a higher aid for that which most nearly concerns our wellbeing.

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REPORTS

ON

THE STATE OF SCIENCE.

*Report of a Committee appointed at the Nottingham Meeting, 1866, for the purpose of Exploring the Plant-beds of North Greenland, consisting of Mr. ROBERT H. SCOTT, Dr. HOOKER, Mr. E. H. WHYMPER, Dr. E. P. WRIGHT, and Sir W. C. TREVELYAN, Bart.**

IN their preliminary Report, which was presented to the Association at the last Meeting, the Committee stated that the sum voted by the Association had been handed over to Mr. Edward Whympcr, one of their members, who was in Greenland at the time of the Meeting.

In the course of the autumn he returned to England, bringing his collection of fossil plants with him.

The Committee then resolved to forward the entire collection to Prof. Heer, at Zurich, for the purposes of identification and description, and they accordingly made application to the Government-Grant Committee of the Royal Society for a grant of money to pay for the carriage of the specimens to and from Zurich.

The Government-Grant Committee, who had formerly assisted the expedition to Greenland by a most liberal grant of money, at once acceded to the second application, and the fossils were sent to Switzerland in the course of last spring (1868).

As soon as they are sent back, a complete series of the specimens will be forwarded to the British Museum, in accordance with the conditions laid down by the Association at the time the money was voted.

The Committee append hereto Mr. Whympcr's Report of his journey, and a notice forwarded by Prof. Heer, giving an account of the most important results obtained by this expedition.

Report of Proceedings to obtain a Collection of Fossil Plants in North Greenland for the Committee of the British Association. By EDWARD WHYMPER.

July 1868.

SIR,—I arrived at the Colony of Jakobshavn, North Greenland, on the 16th of June, 1867, but was unable to start for Atanekrdluk, distant northwards about sixty English miles, before August the 19th. In the meantime I purchased the only boat that could be spared, and obtained as much infor-

* Read at the Norwich Meeting, 1868.

mation as possible from the Danes and from the natives respecting the localities we were about to visit. From the information so obtained, it was evident that the fossil stores on the hill of Atanekerdluk had already been well ransacked, and that we could not hope to meet with any great novelties in that direction. I obtained, however, some amber, through the natives, from a locality on Disco Island, which had not been examined, and heard of two other places where fossil wood had been discovered. These places, Ujarasuksumitok and Kudliset, are described at length further on. I also secured by purchase several specimens from Atanekerdluk, and a few fossil shells from Paitorsik in the district of Umenak*.

We were ready to start by the middle of August, but the natives on whom we had relied for a crew preferred to go south, to a dance at Claushavn; and it was owing to the kindness of the trader at Jakobshavn, who gave us a passage in a blubber-boat returning to Ritenbenk, that we were at length enabled to start on our journey. We got to Ritenbenk at 1.30 A.M. on the 20th of August, and in spite of the inconvenient hour at which we arrived, were received with the greatest warmth and hospitality by Mr. Anderson. On the evening of the same day we again started; this time with a strong force, by the advice of Mr. Anderson, the trader. There were now with me two boats, one hired at Ritenbenk, eleven native men and women, and Messrs. Brown and Tegner (naturalist and interpreter). I tried hard to engage the natives to go as far as Umenak, but failed to get them to promise to go further than Atanekerdluk.

We started at 10.30 P.M., and our course soon took us into the midst of the Tossukatek ice-stream, a great assemblage of icebergs large and small, which were given off from a glacier whose summit we could just see on the horizon. This ice-stream was remarkable for the enormous number of icebergs it contained, and was also notable for the small amount of moraine matter upon them. Really large blocks of rock we did not see, and those of a yard in diameter were rare; but there was abundance of small stones, of grit, and of sand upon the bergs. There is no doubt that beneath the course of the Tossukatek ice-stream, as below all others†, there are conglomerate strata in course of formation, which cannot now be seen, but which may possibly be presented to the view of future travellers.

Shortly after passing through this ice-stream we arrived at the small settlement of Sakkak‡. This place stands by the water's edge at the entrance of a great valley running into the heart of the Noursoak peninsula. A considerable river that flows down this valley falls into the sea a little to the north of the settlement, and appears to form the boundary line of the granite districts which we were just quitting, and the trap formation upon which we were just entering.

A solitary Danish man lives at this place, and has done so for twenty-

*	<i>Astarte sulcata</i> , <i>Coslin</i>.	|	<i>Mya truncata</i> , <i>Fabr.</i>
	— <i>crebricostata</i> , <i>Forbes</i> .		<i>Cardium</i> — ?
	— <i>cliptica</i> , <i>Brown</i> .		

† On the voyage up Davis Straits we were becalmed off Risskol, a noted landmark, and anchored on some banks in eighteen fathoms. These banks have certainly been greatly increased, if not originated, by the deposition of matter from the icebergs of the Jakobshavn ice-stream. At the time we were anchored a large number of small bergs were aground upon them, breaking up and revolving all around. We took the opportunity to put down the dredge, and although we only worked from the ship side, and consequently over a very limited amount of bottom, we brought up in two or three hauls fragments of granite, gneiss (some with garnets), syenite, quartz, hornblende, greenstone, and mica-slate. The sounding-lead showed a fine sand bottom, and the anchor flukes brought fetid mud.

‡ The word Sakkak means, according to Giesecke, "sunside," i. e. southerly aspect.

four years. He says that the glaciers which can be seen from his house, both on the Noursoak peninsula and upon Disco Island, are steadily increasing; so much so that their progress can be noted every year. This statement coincides with the observation of Sir C. Giesecke nearly sixty years ago. The latter says*, speaking of the route to Umenak, "formerly they drove generally over Gamle Riteubenk†, but for several years the road has become impassable in consequence of the 'iceblink' by which the whole continent there is covered. The same will take place with the new road at present in use." The glaciers to the south were, however, as far as I observed them, decidedly shrinking.

At Sakkak we were joined by a native guide for Atanekerdluk, named Gudemann, and also by two others who volunteered their services. We continued our journey after a brief halt, and arrived at our destination shortly after 1 A.M. on August the 22nd.

The name Atanekerdluk is applied by the natives to a basaltic peninsula, about half a mile in length, connected with the mainland by a sandy neck, which is apparently covered by the sea at spring-tides. A bay with a sandy beach stretches about two miles to the south, and at its further extremity there is another promontory, of columnar basalt, named Imnarsoit. Between these two promontories, and indeed along the whole of the shore from the above-mentioned valley at Sakkak to the most northern point of the Noursoak peninsula, mountains rise from the water's edge and attain in some places a height of 5000 to 6000 feet. Behind the peninsula of Atanekerdluk they do not, however, attain a height greater than 3600 or 3800 feet. They are cut up by numerous small valleys and ravines.

The position of Atanekerdluk is indicated at a great distance by means of three mountain-peaks of symmetrical form. The fossil bed is one-third way up the most northern of these, and between it and the central one. Under the guidance of Gudemann we started for it at midday on the 22nd. The sides of the hill on which it is situate (an outlying buttress of the mountain already mentioned) were of considerable steepness, and channelled in many places by small streams. It was mainly composed of sand and of shales, and was strewn with disintegrated fragments of hardened clays, sandstones, and basalt. The most prominent features were the dykes of trap which appeared in numerous places‡, sometimes as regular in form as built walls, and in others picturesque as Rhine castles. Five, if not six, of these dykes appeared at different places in the section of the coast between the headlands of Atanekerdluk and Imnarsoit.

It has been already mentioned that this locality had been frequently visited§ before 1867 for the sake of its fossil deposit. This was evident by numerous fragments that we found in the course of our ascent, which had been dropped by others in descending, and it seemed at first as if the deposit was very extensive. We found it in fact to be confined within narrow limits. It did not appear to extend a greater length than 400 feet, with a maximum depth of 150 feet. In most places the portion exposed was nothing more than a seam a few feet in depth. It was on a shelf of the hill at the height of 1175 feet||; the southern end was exposed on the north side

* Giesecke's MS. Journal, year 1811.

† The Danish name for the settlement of Sakkak.

‡ These, as well as the other points of Atanekerdluk, were illustrated by a reference to a photograph of a drawing made from my sketch taken on the spot.

§ By Danes, or by natives collecting for Danes.

|| The mean of eight observations by aneroid. Capt. Inglefield gives the height 1084 feet.

of the most prominent of the ravines already referred to. The length of the deposit, that is to say the face of the hill on which it was found, fronted the Waigat, due west, magnetic.

I took from England, besides hammers, picks, and shovels, all the necessaries for blasting; but these latter were unnecessary. The seam was for the most part enclosed by sand, and specimens were obtained with ease. The division of labour was as follows:—The natives (fourteen) collected, Mr. Tegner interpreted, and I selected. I directed Mr. Brown to collect specimens of the different strata in order that sections might be prepared*. The specimens are before me, and comprise:—basalt; sandstone containing nodules of basalt rather smaller than an ordinary walnut; indurated black mud, probably derived from decomposed basaltic rock; limestone; calcareous mud, containing lime and alumina; calcareous mud with layers of vegetable matter; sandstones of different degrees of fineness; sandstone containing a large amount of alumina; coarse sandstone, about equivalent to the millstone grit of Derbyshire and Yorkshire; coarse conglomerate sandstone, with fragments of silica about the size of common horse-beans; calcareous sandstones of different degrees of fineness (effervescing readily when hydrochloric acid is applied); fine-grained calcareous sandstone, in which the lime effervesces when hydrochloric acid is applied, and containing mica distributed in patches with silica; calcareous sandstone, with layers of vegetable matter; ferruginous conglomerate (grains of quartz, cemented together by oxide of iron); hard clay of black colour; fine hardened mud containing vegetable impressions; streaks of clay, with layers of coal one-sixteenth of an inch thick; bituminous shale; and lignite†. After a hard day's work we returned to our camp, in a ruined native house by the shore. It froze sharply during the night.

On the 23rd we resumed work, and by the close of the day had made a large collection of good specimens. It was my endeavour to select, as far as possible, perfect specimens of individual species, rather than fine slabs containing numerous species. Unfortunately a large number of the finest specimens were irremediably smashed in transit down the hill; this was due much more to the brittleness of the specimens and the steepness of the descent than to carelessness. The natives indeed worked admirably.

On the 24th we finished our work at this locality. A trench had been dug by this time 20 feet in length, to a depth of 5 feet, completely through the seam, and the section showed:—

	ft.	in.
1. Stratum of fine sand, light grey colour	1	7 deep.
2. " similar to No. 1, darker	8	"
3. " fine white sand	8	"
4. " similar to No. 2	9	"
5. " " No. 3	6	"
6. " yellow sand.		

The impressions of leaves were found for the most part in stratum No. 1, or upon the surface; they were also obtained from Nos. 2, 3, 4, but I believe not lower. Those found in the uppermost and upon the surface were ordinarily in hard clay, red in colour, due to oxide of iron. These did not suffer much by transportation; but the surface had apparently undergone a careful scrutiny, and few very perfect specimens were obtained from it.

* The sections have not yet been handed to me.

† These specimens have been named by Prof. J. Tennant, who has obliged me by examining and naming all the specimens referred to in this Report.

The impressions in the softer and more brittle shales were obtained some depth below the surface; these yielded the best specimens, but they suffered greatly in transit. Those found at the greatest depth were almost invariably in lumps of hard clay that fractured irregularly; these differed from the others in being of an iron-grey colour. They have reddened since they have been exposed to the atmosphere. The trench was dug about midway between the extremes of the deposit, and examination at other points showed a similar arrangement. The hill at this part was mainly composed of sand, enclosing numerous thin seams of brittle indurated clay, red in colour, containing a good deal of iron and of moderately fine-grained sandstones.

We were unable to find the "perfect stem, standing four feet out of the side of the hill," spoken of by Capt. Inglesfield*, and it was unknown to the natives. It was said to have stood on the edge of a precipice, in the ravine on the south of the hill, and it has probably been buried in a fall that appears to have taken place not very long ago. In the sides of this ravine, both above and below the leaf-deposit, numerous beds of lignite are exposed, at least one being of considerable thickness. I brought home from this bed a block 1 foot 9 inches in thickness, a portion of which has been analyzed in the laboratory of Mr. T. W. Keates of Chatham Place, with the following result:—

"Specific gravity		1.369	
Gaseous and volatile matter		45.45	
Moisture		.75	
			46.20
Sulphur			.55
Coke {	Fixed carbon	47.75	
	Ash	5.50	
			53.25
			100.00

The lignite contains a trace of bitumen; the coke is non-caking, and of little use."

In this lignite we found small pieces of amber, the largest being about the size of a common pea. We also found amber, but in still smaller fragments, in the leaf-deposit itself. It was nowhere abundant.

The scantiness of the living vegetation at Atanekerdluk offered a marked contrast to the luxuriance displayed in the leaf-deposit. Although this was the sunny side of the Waigat Strait and the hills were completely free from snow, vegetation was as meagre as upon Disco Island itself. The drifting of the sand accounts for this doubtless to some extent. The largest dead wood measured less than an inch and a half in diameter, and the largest growing wood less than an inch.

The most remarkable natural object at Atanekerdluk is a trap pinnacle†. The surrounding soil has been removed, leaving this portion of a former dyke standing perfectly isolated. Its height is about eighty feet.

On the evening of August the 24th we rowed across the Waigat to a little settlement on Disco Island, named Unartuvarsok, immediately opposite to Atanekerdluk. At this part the Waigat is nearly twelve miles across, and its passage took us more than four hours.

* Private Journal of Capt. E. A. Inglesfield, quoted in "A Report on the Miocene Flora of North Greenland," by Prof. O. Heer, 1866. Journal of the Royal Dublin Society, vol. iv.

† A photograph of which from a drawing made from a sketch taken on the spot was exhibited.

Unartuvarsok is now the only inhabited place on the whole of the Waigat side of Disco Island, and the sole inducement to visit it lay in the expectation that we should be able to find a native who knew the localities of Ujarasuksumitok and Kudliset. In this we were not disappointed; the native catechist (teacher) offered to act as guide, and moreover invited us to pass the night in his house. We did so, and found the atmosphere most filthy.

Early on the following morning we again started, passing at a short distance from the settlement some remarkable peaks that stood in advance of the great basaltic cliffs which are the chief features of Disco Island. These cliffs are everywhere crowned by glaciers, which occasionally, but rarely on the Waigat side of the island, pour over and advance towards the shore. Near the settlement of Unartuvarsok there are two or three points, at least, at which this glacier-plateau could be reached without much difficulty*.

Coal-seams are exposed at a number of points both along the Waigat and on the coast between Flakkerhuk and Godhavn. Dr. Rink mentions† five places at which it is found along these shores; there are at least three others,—one spoken of by Giesecke; another near to Issungvak Ness, from which I obtained amber through the natives; and a third nearer to Godhavn. At the time of our visit fossil wood had been found:—1st, at Igltusiak, near Godhavn; 2nd, at Signifik, between the last-named place and Flakkerhuk; 3rd, at Ujarasuk (Ujarasuksumitok); and 4th, at Kulfelden (Kudliset). Specimens from these places are in the University Museum at Copenhagen, and on my return I obtained, through the courtesy of Professor Johnstrup, duplicate specimens from the first two named. Until the time of our visit leaves had not, however, been found, with the exception of a few specimens by Dr. Lyall. Amber had, however, been found at several places; and from this fact, and from the statement by Giesecke that he had himself observed impressions of leaves (apparently *Angelica Archangelica*), there was little doubt but that a more careful search would yield results. It was most important to find the place spoken of by Giesecke as Ritenbenk's Kulbrund. There was difficulty in doing so: the natives differed among themselves; but we now know that this name is applied equally to all the places along the Waigat coast of Disco from which coal has been taken for Ritenbenk. At the present time coal for that colony is only taken from one place on Disco, namely, Ujarasuksumitok; but it has been taken from several others, and hence we were much puzzled to determine the precise point to which Giesecke referred.

On arrival at Ujarasuksumitok it was found that the coal was exposed in the cliff by the shore, at a height of about fifty feet above the sea. It had been worked a length of fifty feet to a depth of four and a half: one could not say what was the entire depth of the seam, as the lower part was covered up by debris. All the natives were put to work, but for some hours we failed to find anything more than wood (up to five inches diameter), charred stems,

* The coast-line of the Waigat strait is laid down very inaccurately in existing maps. The chart of Dr. Rink, which is probably the best, makes the Disco coast very nearly a straight line from the promontory called Issungvak Ness to the shores opposite to Hare Island. In fact the coast-line from the above-named point to halfway up the strait is formed by one great bay that includes numerous smaller ones. We coasted these, and remarked that for a considerable distance from the shore they were extremely shallow. At a distance of a half English mile, or even more, there were places with a depth of only eight or nine feet. The whole of the Waigat, indeed, appeared to be shallow. Small icebergs were aground in numerous places in the very centre of it.

† Grönland Geographisk og Statistisk beskrevet, vol. i. pp. 172, &c.

doubtful impressions, and a few grains of amber. I then went along the coast towards the north, and was at length rewarded by finding a fair specimen, containing leaves, in the bed of a small stream. It was in hardened, warm-coloured clay, similar to that obtained at Atanekordluk. I followed the stream to its source, a height of about 1000 feet, without finding anything more. Then returning, I went to the south, and in another and larger torrent-bed found several others. The natives, now put on the right track, soon brought in a fair collection. Gudemann was the fortunate discoverer of the *Magnolia* cone, to which Prof. Heer refers, and he was greatly surprised at the reward it produced him.

All the specimens collected at this place were obtained from these two torrent-beds: Mr. Brown, who followed the fossils up to their source, reported that they came from a thin seam difficult to get at. As it was becoming a question whether the boats would carry all the specimens we had already collected, I decided to push onwards the same night to Kudliset, which, from reports received, seemed a more promising place for investigation.

We arrived there about midnight, and camped very smartly. The weather had already become sufficiently cold to freeze the salt water in the bays at night, and during the whole day fresh water remained frozen in the little pools on the land. The whole of this part of Disco Island was very dismal. Its aspect allows the sun to shine upon it for but a small portion of the day*, and all animal life seemed to shun it. A few ptarmigan were the only living creatures we saw on the land during the days we passed on these shores. There was little wonder that the natives were already wishing to return. They were ill-protected from the weather; for, from reasons which need not be mentioned, it was impossible to allow them to enter the tents, and they had only such shelter as they could obtain by piling up turf and stones, and covering themselves with a few small blankets and spare skins which we had brought with us.

At this place (Kudliset) coal (lignite) was exposed in a cliff on the south side of the bed of a small stream in two seams, 4 feet apart, for a length of about 30 feet, difficult to get at. They were 105 feet (by aneroid) above the sea, and distant from it about 300 yards. The lowest seam, 2 feet thick, was resting on a bed of indurated clay, and between the seams was a coarse and very loose, crumbly sandstone. The uppermost seam, one foot thick, was capped by a finer and harder sandstone which I could not measure. The whole, above and below, was enclosed by sand.

In the torrent-bed we quickly found some considerable masses of fossilized wood, and I followed the stream upwards in hopes of finding leaves. At a height of about 800 feet I obtained agates in basalt, and following the stream to its source (about 1000 feet above the sea), came nearly to the foot of the great basaltic cliffs. The specimens collected here include hardened clays which have taken form in cavities in the basalt. Returning to my party I found that they had in the meantime obtained some indifferent and fair specimens from the torrent-bed, and from the sandstone above the coal. We afterwards added to their number, but the coarseness of the stone prevented any very good specimens from being obtained. We also secured some good specimens of fossil wood, about one foot in diameter. Nodules of argil-

* The Danish man at Sakkak informed me that the coal was got out easily enough during the summer time, but that at a depth of 12 feet it remained frozen throughout the year. On arriving at the frozen coal, they commonly wait two or three days to allow it to thaw, before continuing to work it.

laceous oxide of iron, having usually in the centre kernels of the same, were abundant in the stream and in the soil at its sides.

After a half-day's work we had apparently exhausted this locality. The specimens obtained were again chiefly taken from the torrent-bed. It was a matter of difficulty, if not of danger, to get any from the sandstone above the coal; and as the natives were murmuring frequently at being taken away further than they had agreed, I sent Mr. Brown to the south with one boat, to examine the coast, and then proceed to Ritenbenk, *via* Atanekerdluk, while I went with the other boat as far north along the Disco shore as the natives would go. A little further along the coast I found some doubtful impressions of leaves in a great wilderness of stones brought down by a glacier-torrent, and about three miles still further north came to the magnificent gorge in the sandstone cliffs by the shore, to which I have vainly endeavoured to do justice in the view exhibited*. One mile after this the cliffs by the shore came to an end, and the coast apparently continued quite flat until opposite Hare Island. The natives agreed that no coal was visible along the whole of this shore, and we crossed to Mannik, on the opposite side of the Waigat. Here there was a small thin seam of coal, exposed in a cliff not far from the shore; but I obtained nothing from it, and we continued our course to Atanekerdluk, arriving shortly after midnight: here we passed the night of the 27th August. The next day was occupied in loading the boat with the specimens we had left there, in sketching, and in completing the examination of the locality. At 4 p.m. we started for Sakkak, and left it at 8.30, arriving at Ritenbenk on the morning of the 29th August. Mr. Brown had arrived about twelve hours before, but, like ourselves, had failed to make any fresh discoveries.

At Ritenbenk we remained three days, with foul weather. During this time the collections, including many hundred specimens, amounting to considerably more than half a ton in weight, were repacked. We were then favoured, by the kindness of Mr. Anderson, with a passage in a blubber-boat to Godhavn, at which place we arrived on September the 4th, after a most disagreeable voyage. On the 10th we sailed on board the brig 'Hølsfiken,' and arrived at Copenhagen on October the 22nd.

In conclusion it is right to observe that these collections could not have been made excepting by means of the facilities afforded by the Danish authorities. We may feel a natural satisfaction that so many as eighty species should have been discovered by the labours of Professor Heer; but it should be remembered that they are primarily due to the invaluable information given by Herr C. S. M. Orik, the Director of the Greenland Trade. Scarcely less are our thanks due to Herr K. Smith, the present Inspector of North Greenland, and to Herr Anderson, of Ritenbenk; both of these gentlemen gave much assistance, at considerable personal trouble, which was of the greatest service.

To Robert H. Scott, Esq.,
Secretary of the Committee of
the British Association.

EDWARD WHYMPER.

Preliminary Report on the Fossil Plants collected by Mr. Whymper in North Greenland, in 1867. By Prof. OSWALD HEER.

The fossil plants which have been sent to me by Mr. Whymper have come partly from Disco Island and partly from Atanekerdluk.

* At this part some boulders of granite, probably transported by sea-ice, were lying on the shore.

The specimens from Disco occur in a coarse-grained sandstone which is at times yellowish, and at times reddish-grey. They were collected at two localities on the eastern side of the island, on the shore of the Waigat, in lat. 70°, or thereabouts. One of these is named Kudlisot (Kudlisot), the other is Ujararsusuk (Ujararsuksumitok), and lies some miles to the south of Kudlisot. This place is also called Ritenbenk's coal-mine, because of a considerable seam of brown coal which occurs in the sandstone, and is sometimes wrought by the colonists of Ritenbenk.

The collection contains thirteen species from these two localities, viz. eleven from Kudlisot, and six from Ujararsusuk; four species are common to both. Two of these may be described as the commonest trees of the district. One is a conifer (*Sequoia Couttsiae*), the other a plane. The collection contains splendid specimens of the *Sequoia*; and with one twig from Ujararsusuk we find the scales of the cone in good preservation, while among the delicate twigs from Kudlisot there is an entire cone. The twigs and cones are precisely similar to those which are so common at Bovey Tracey in Devonshire, and which have also been found in the Hempstead beds in the Isle of Wight. This remarkable tree, which I have described as *Sequoia Couttsiae*, and which is closely allied to *Sequoia gigantea* (*Wellingtonia gigantea*, Lindl.), extends accordingly from the south of England to North Greenland, and has ripened its fruit in the latter region. Not less remarkable is the plane, of which the collection contains very fine leaves; it resembles the American plane, from which it is not easily distinguishable.

Among the other plants from this locality we may name a fern (*Aspidium Meyeri*), which is covered with fruit, a reed, the amber-tree of Europe (*Liquidambar Europæum*, Braun), a Christ-thorn (*Paliurus Colombi*), and a *Dryandra* (*D. acutiloba*), which was only known to occur in the Wetterau and at Bilin, in Bohemia.

The most remarkable discovery, without doubt, is that of two cones of *Magnolia*. In my 'Flora Arctica' I have already identified the leaves of a *Magnolia* (*M. Inglefieldi*), and have shown that in respect of their size and leathery texture they approach those of *M. grandiflora*, L. Now we find these cones coming to light and confirming the identification of the leaves. In addition to a cone of the same size as that of *M. grandiflora*, there is a spray with a large bud, very similar to those of *Magnolia*. At Kudlisot several fragments of leaves were collected.

Of the thirteen species from Disco three are entirely new, and besides seven had not previously been recognized as Greenland species.

Atanekordluk lies on the opposite side of the Waigat, on the peninsula of Noursok, and in the same latitude as Kudlisot. This locality has already afforded the abundant collections which have been brought to Dublin and London, and to Copenhagen and Stockholm, and which are described in my 'Flora Fossilis Arctica.' At this place Mr. Whynper has collected a great number of plants, in fact the greater portion of his collection. The majority of the species contained in the slabs were already known, as might have been expected. The Poplars and *Sequoie* (*S. Langsdorffii*, Brgn.) are very abundant, and the twigs and leaves at times cover the entire surface of the stone. We can recognize the male and female flowers in addition to the cones. The *McClintockias*, which are in themselves so remarkable, and the leaves of oaks and hazelnuts are not rare, and are sometimes very well preserved.

I have hitherto recognized sixty species; but as many of the slabs have not yet been worked out, it is probable that this number will be increased. One-fourth of these, i. e. fifteen species, are new, or at least new to Greenland, and of these the following deserve special notice:—

1. A *Sassafras* (*Sassafras Ferretianum*), closely allied to the North-American species. This species I had obtained from Menat in France, and it also occurs at Senegaglia.

2. The fruit of a *Nyssa*, like a species from Bovey and from Salzhausen.

3. A very perfect leaf of a Snowball (*Viburnum Wimperii*, Hr.).

4. Leathery leaves of a plant which probably belongs to the Aralias (*Aralia Browniana*, Hr.).

5. A new species of *Cornus* and a new *Cratægeus*.

Important though the discovery of these new species is as extending our knowledge of the Miocene Flora, it is not more so than the additional information as to known Arctic forms which has been afforded by this expedition, as tending to correct, or rather to confirm their identifications.

Among these we should name a very beautiful Fern (*Hemitellites Torellii*), which differs widely from all those of the temperate zone; the leaf-part of a *Salishuria*, which in its form approaches very closely to the Japanese species; a perfect leaf of *Quercus Lyellii*, Hr.; the leaf of a Vine (*Vitis arctica*, Hr.); several fragments of leaves of nut-trees, and of *Magnolia Inglefieldii*; and the fruit of *Menyanthes*, which species I have already identified by means of the leaves.

On the whole the collection contains sixty-seven species, of which twenty-two are new to Greenland, and are accordingly additions to our knowledge of the fossil flora of the Arctic Zone.

To these may be added three specimens of the fauna, two insects and a bivalve. One of the insects exhibits elytra in very good preservation, and belongs to the Coleoptera, the other to the Hemiptera. The bivalve is a freshwater species (*Cyclas*), and confirms the view that the deposit of Atanekerdluk, which contains so many plants, is a freshwater formation.

Report of a Committee, consisting of Mr. C. W. MERRIFIELD, F.R.S., Mr. G. P. BIDDER, Captain DOUGLAS GALTON, F.R.S., Mr. F. GALTON, F.R.S., Professor RANKINE, F.R.S., and Mr. W. FROUDE, appointed to report on the state of existing knowledge on the Stability, Propulsion, and Sea-going Qualities of Ships, and as to the application which it may be desirable to make to Her Majesty's Government on these subjects. Prepared for the Committee by C. W. MERRIFIELD, F.R.S.

THE subject referred to us is a very large one, and having regard both to the space which a complete report on such a matter would require and to the time at our disposal for making it, we have thought it best to lay before the present Meeting a First Report, in which we confine ourselves to the *resistance which ships offer to propulsion*, and to their *behaviour in respect of rolling*. These are, in their several directions, the preliminary subjects necessary to the inquiry committed to us; and they are also the parts of naval science on which exact experiment appears to be most urgently needed, both for the direct knowledge of these branches, and also as a foundation for experiments on propulsion and the other applications which depend upon them. Knowledge of the work to be done should precede the selection of the tool with which it is to be performed,

RESISTANCE.

Total Resistance.

The question of resistance may be treated in two ways,—either in gross, as regarding the power required to drive a vessel of certain form and dimensions at a specified rate; or in detail, as regarding the exact way in which the vessel and the propeller act and react upon the water which they disturb. Hitherto there has been but little connexion established between the phenomena of detail and the general result, the former not being understood with any reasonable degree of certainty, and the latter also being far from settled with precision.

The variable elements which go to make resistance what it is are chiefly velocity, form, condition of surface, and absolute dimension. The effect of form is as varied as the number of forms which can be given to a floating body. As regards dimension, assuming the forms to be geometrically the same, it has been found that vessels of different absolute size do not correspond in the degree of resistance which they encounter, whether in smooth water or in waves. It will also be seen that the absolute length of a ship, considered irrespectively of breadth or depth, has a direct influence on the resistance.

As regards velocity, it is usual to assume, in books on hydrodynamics, that the resistance of water varies as the square of the speed. For the purposes of naval architecture, this can only be taken to be roughly true under certain limiting conditions, beyond which the law of the squares deviates widely from the observed facts. It appears to be probable that this increase, as the square of the speed, is rather a minimum than a general rule of increase, and that such a minimum is only attained by ships of good form, and of a length which is a certain function of the speed. The vague words *good form* are used designedly, it being still uncertain what the best form may be, and what extent of deviation from it takes the vessel out of its operation. When the vessel is shorter than a certain limit of length depending on the velocity, the resistance seems to increase more rapidly than the square, and the power needed to drive the ship consequently increases faster than the cube of the velocity.

It may save confusion to remark that the measure of *resistance* is referred to a unit of distance, while *power* is referred to a unit of time. For any law of resistance, therefore, the power varies as the product of the resistance and speed, and where the velocity varies we have simply to use the corresponding integral formula.

As already remarked, the *leading formulæ* of the resistance of water are

$$R \propto V^2, \text{ H.P.} \propto R V \propto V^3,$$

the latter being the strictly necessary consequence of the former. There is but little disagreement among writers up to this point. But the moment we attempt either to assign values to the constants of the equations which they imply, or to introduce the corrections depending on the complex phenomena, which always, more or less, mask the mere question of fluid resistance, we find very little agreement.

The chief elements of the resistance of water to a body moving through it are:—

(1) The *direct head-resistance* due to the work of thrusting the water to the right and left, with or without vertical motion, in order to make way for the body to pass.

(2) The *skin-resistance*, or friction of the water on the surface of the moving body, combined with the effect of surface eddies and other minute phenomena.

(3) The *back pressure*, due to the diminished pressure in rear of the moving body and in wake of any corners or unfairness of surface which may cause eddies.

(4) In addition to these, there are the phenomena of capillarity and of the viscosity of water. These are of importance as regards minute bodies, including even small models; but for large ships they are sufficiently accounted for in the arbitrary constant of skin-resistance. This fourth head may therefore be neglected, except when we wish to pass from ships to models.

For extreme shapes it does not appear that the three leading elements of resistance can be grouped under one term; but there is reason to believe that, for vessels of a certain form, they all involve, with a respectable degree of approximation, the square of the velocity, and also that the forms for which this is true are among those which offer, *ceteris paribus*, the least resistance. Under these circumstances, the formulæ depending on skin-resistance may be made to include the other two by merely altering the constants. We conjecture that, when authors state that certain elements of resistance may practically be neglected, they usually mean that they can be accounted for in assigning the values to the arbitrary constants, which, in any case, must be determined from experiment. We have named vessels of a certain form; this form must be regarded as still unknown, except with reference to some limitations of a negative character, even these being rather indefinite. They include a fine entrance, and a fine run, and an absolute length of not less than the length of the trochoidal wave moving with the same velocity. The actual determination of the form of least resistance is not only unsolved, but the data of the problem are yet unknown.

The first formulæ that occur are the well-known coefficients of steam-ship performance—

$$\frac{(\text{Speed})^3 \times (\text{displacement})^{\frac{1}{2}}}{\text{Indicated horse-power}}$$

$$\frac{(\text{Speed})^3 \times \text{area of midship section}}{\text{Indicated horse-power}}$$

As affording a rough measure of comparison, the tabulation of these formulæ for different ships is extremely convenient. But they are of very little assistance in settling a theory. Even for the same vessel, tried under apparently similar conditions, these coefficients do not appear to be constant quantities. Moreover, the varying efficiency of the steam-engine and of the propeller, considered as machines for the transmission of power, are inseparably grouped with the work of overcoming resistance. When the consumption of coal is substituted for the I.H.P., the efficiency of the furnace and boiler also comes in. Some of these remarks apply to Mr. Hawksley's approximate formula,—

$$\text{Velocity in statute miles} = 27 \left(\frac{\text{effective horse-power}}{\text{wetted surface in } \Pi'} \right)^{\frac{1}{2}};$$

but this was only intended for rough purposes.

We may here mention a formula given by Mr. Greene, in a paper read at the Franklin Institute of New York, and reprinted in the 'Mechanics' Magazine' for 8th July, 1864. It proceeds on the assumption that the power

expended in overcoming back pressure and friction in the engine varies directly as the speed—

$$H.P. = D^{\frac{1}{2}} V (.1552 + .0046846 V^2),$$

the constants being obtained empirically.

Most modern formulæ for resistance take account of the form of the vessel, in such a manner as to require the use of the drawings of the exterior surface of the ship. The Swede, Chapman, in his well-known treatise on ship-building, assumes that the surface of the vessel may be divided into small portions, the resistance of each of which will be proportional to the projection of its area, to the sine squared of the inclination, and to the square of the velocity; with a certain small correction on account of the currents which are set up by the ship's own motion, and which modify the pressures. But he himself saw reason from subsequent experiments to doubt whether the law of the sine squared, or even that of the velocity squared, was applicable to the forms which he used.

Euler* and most of the older writers use the sine squared of the inclination as the factor representing the effect of obliquity; and this theory has been revived by Mr. Hawksley in a discussion at the Institution of Civil Engineers, reported in their 'Proceedings' for 1856, vol. xvi. p. 356. But we think that there is now ample experimental ground for believing that, whether or not this law be true with respect to an infinitesimal portion of a plane receiving the impact of a thin jet of water, it is not true either of plane surfaces of considerable extent, or, as a differential formula, of curved surfaces. It evidently fails to take account of the effect of the stream which is set up along the surface in deflecting the impact of water on the part of the surface further back from the entrance. The assumption that this has no effect is not one which can be admitted without proof; and the experimental evidence tends the other way. Chapman's later experiments, the experiments of the French Academy, and those of Col. Beaufoy† are all against the hypothesis of the sine squared of the inclination. The supposition that the sine squared of the inclination represents the effect of the obliquity of the afterbody is still more open to doubt than when it is applied to the forebody.

As a contribution to the history of the subject, the following translation from a tract of M. Dupuy de Lôme will be interesting:—

"Romme, in his Memoir for the Academy of Sciences, in 1784, while giving an account of the experiments made by him at Rochefort on models of ships, one of which represented a 74, and, again, in his work on the 'Art de la Marine,' had very succinctly laid down that this resistance was independent of form. 'Provided,' he went on to say, 'the water-lines have a regular, fair curvature, as is the case in modern vessels, the greater or less fullness of the bow or stern neither increases nor diminishes the resistance of the water to their progress.'

"In direct contradiction to this too summary rule, which has long obstructed the progress of naval architecture, my experience leads to five principles, which I state as follows:—

"1°. Among vessels of similar geometrical form, of different size, but all having their immersed surface exceedingly smooth, and driven at the same

* See his 'Scientia Navalis' (St. Petersburg, 1749), vol. i. p. 213. See also D'Alembert, 'Traité de l'Equilibre et du Mouvement des Fluides,' ed. of 1770, p. 226.

† See Chapman (by Inman), p. 257; Bossut, 'Hydrodynamique,' vol. ii. p. 396; Beaufoy, p. lxxxvii. See also Scott Russell's 'Naval Architecture,' p. 168; or Proceedings of Civil Engineers, vol. xxiii. p. 346, as to the French experiments.

speed, the pressure needed to attain this speed increases more slowly than the surface of the greatest transverse section. It is near the truth to say that, for similar forms, the resistance per square metre of midship section, at the same speed, decreases as the vessel increases, in the ratio of the square roots of the radii of curvature of its lines, these radii being themselves proportional to the linear dimensions of the ships; it is therefore wrong to compare the resistance of different ships by means of experiments made on models to reduced scales[‡].

“2°. If the same vessel be driven at different speeds, the force needed to obtain these velocities increases less rapidly than the square of the speed, while that is small. The force increases as the square for ordinary rates of 3 to 5 metres per second, according to the condition of the surface in respect of smoothness. Beyond that speed it increases faster than the square[†].

“3°. The diminution of the angle of entrance, and the lengthening of the radius of curvature of the lines which the water has to follow, especially in the replacement in wake of the stern by the water coming up from below, are the principal means of diminishing the resistance. This has the greater influence the greater the driving-power. For very slow motion, the influence of form is less than that of surface friction.

“4°. The sharpness of the bow, both above and below the water-line, which has in calm water the effect just mentioned, has more marked advantages in a heavy sea-way.

“5°. The smoothness of the wetted surface plays a considerable part in the resistance; and this part, due to friction, varies but little with the speed.

“I add that the resistance of the hull increases markedly in narrow channels, and still more where the depth of water does not much exceed the draught of the ship; so that experiments ought to be made in deep water.

“Finally, my numerous observations on the resistance of ships, in calm weather and open sea, agree, with a close approach to exactness, with the following formula, which I have since adopted as the measure of the resistance:—

$$R=KS(V^2+0.145V^3)+K'S^3\sqrt{V}.$$

“In this formula, I call—

S, the area of midship section in square inches.

S', the product of the mean girth (wetted), into the extreme length, also in square metres.

V, the speed in metres per second.

K, a coefficient varying with the form, diminishing inversely as the square root of the radii of the curvature of the longitudinal sections, and also diminishing with the mean angle of entrance. This second reduction amounts to about 15 per cent., as the mean angle of entrance comes down from 45° to 15°. It is therefore about $\frac{1}{2}$ per cent. for each degree between those limits.

K', a coefficient independent of the form, and varying only with the smoothness of the wet skin. This coefficient may increase in the ratio of 1 to 10, from 0.3 for bottoms very smoothly covered with good copper,

* M. Récé, Director of the Ecole d'Application du Génie Maritime, has long since pointed out in his lectures the error frequently made of comparing the resistance of vessels of various forms by means of experiments upon models driven at the speed proper to the vessels themselves.—*Note by the French author.*

† I am here speaking of vessels only partially immersed, not of vessels which are entirely under water.—*Note by the French author.*

and the heads of the nails well beaten down, to 3.0 for hulls covered with weed and barnacles.

R is the resistance expressed in kilogrammes, and corresponding to the speed V.

"For each ship experimented upon, two trials are sufficient to determine K and K'.

"For the 'Napoléon,' while clean, the copper being oxidized, not greased, I found

$$K=1.96, \quad K'=0.44,$$

from which I obtain for the general expression for the resistance to the passage of the ship through the water,

$$R=1.96S(V^2+0.145V^3)+0.440S^{\frac{1}{2}}\sqrt{V}.$$

A Table previously given shows that during the trial trip of the 'Napoléon' the values of S and S' were—

S between 99 and 100 square metres.

S' between 1580 and 1610 square metres.

* * *

"The power needed to obtain this speed is obtained from this calculation by multiplying the resistance, so calculated, by the velocity."

The above remarks are translated from a memoir published by M. Dupuy de Lôme on the occasion of his candidature for the French Academy in 1865-66. It is reprinted in M. Flachat's 'Navigation à Vapeur Transocéanique,' vol. i. p. 206.

It may not be out of place to mention, in explanation of M. Dupuy de Lôme's remarks about the angle of entrance, that the architects of the Imperial Navy avoid the use of the hollow bow. There is at most a slight concavity at the fore-foot. Hence the angle of entrance has a meaning which is sometimes lost in modern English practice.

M. Bourgois, in his memoir* on the resistance of water, gives formulæ which may be grouped under the general form of

$$R=B^2V^2\left[K_1+K_2\frac{lV^2}{B^2}+K_3\frac{S}{B^2V}\right],$$

B² being the area of midship section, S the wet surface, and l the breadth extreme. K₁, K₂, and K₃ are constants which vary with different classes of vessels.

The dependence of the resistance of ships upon the theory of waves appears to have been first insisted upon by Mr. Scott Russell. That gentleman seems to have been the first to discover that there was a relation between the length of the ship and the velocity of advantageous propulsion, this relation being taken directly from the theories of the solitary and of the trochoidal waves. We will state his theory of resistance in as few words as possible.

Scott Russell's Theory of the Form of Least Resistance.

A vessel may be divided longitudinally into three portions, bow, straight middlebody (if any), and afterbody. The midship section may be of any shape whatever, the resistance due to it depending on its area and wet

* Published at Paris, by Arthur Bertrand, s.a. See also Sonnet, 'Dictionnaire des Mathématiques Appliquées,' art. "Résistance des Fluides."

girth only. The forebody must have for its level sections curves of sines (harmonic curves) whose equation may be written as

$$x = \frac{l\theta}{\pi}, \quad y = \frac{1}{2}b(1 + \cos \theta),$$

b being the half breadth of the ship at any level, and l the length of the forebody, which must not be less than the length of the "solitary wave," which has the same speed as the ship is intended to have, in order that the resistance may be the least possible. The afterbody is to have trochoids for its level lines, their equation being

$$x = \frac{l'\theta}{\pi} + \frac{1}{2}b \sin \theta, \quad y = \frac{1}{2}b(1 + \cos \theta),$$

l' being the length of the afterbody, which is not to be less than that of one half of the oscillating or trochoidal wave of the same speed as the ship. The straight middlebody may be of any length whatever, as it will only affect the resistance by increasing the surface for friction; or, subject to these conditions, the resistance of the ship will be expressed by

$$(K \oplus + K'S) V^2,$$

where $\oplus$ represents the area of midship section, and S the wetted surface. K and K' are coefficients, the former of which may be roughly stated at $\frac{1}{10}$ of that due to a flat plate drawn flatwise through the water, and the latter depending upon the condition of the surface. For a pure wedge bow, whose angle is ϵ , Mr. Scott Russell considers that the resistance varies as $\left(\frac{\pi}{2\pi - \epsilon}\right)^2$, ϵ lying between the limits of 12° and 144° ; and where the bow is compounded of this and of the wave form, he gives, as a rough measure of the resistance, a formula obtained by compounding this, in such proportion as may properly represent the geometrical combination of form, with the resistance due to the wave form.

As far as can be judged by Mr. Scott Russell's published writings, there appears to be some unsettled ground in his theory relatively to the shape of the afterbody. The form of the bow is simply that of one-half the profile of a solitary wave of translation, laid horizontally instead of vertically. The form of the stern is also taken from the form of the wave, which is set up when a hollow in the surface of water has to be filled up; but it is nowhere made clear whether this form ought to be given to the level sections, or to the vertical longitudinal sections, or whether some compromise should be made between the two; and it seems probable that the author himself was doubtful on the subject. The experiments recently made under the direction of the Committee of the British Association appointed to make experiments on the difference between the resistance of water to floating and immersed bodies (Report for 1866, p. 148) seem to indicate that that doubt is still unsettled.

Without hazarding an opinion as to whether this form is really that of least resistance, it appears certain that the curves used are among those along which fluid particles can glide smoothly, without causing supernumerary diverging waves in the liquid.

The general formula for the length of a ship given by this theory is:—

$$\text{Forebody in feet} = \frac{2\pi}{g} V^2 \text{ in feet per second;}$$

$$\text{Afterbody} = \frac{4\pi}{3g} V^2 \text{ in feet per second.}$$

The following are the values of the factor and its logarithm, which give the length of the forebody in feet, when the velocity is given in—

Feet, per second.	0.19518	log = 9.29045.
Knots, per hour	0.5561	log = 9.74515.
Statute miles, per hour ..	0.41985	log = 9.62310.

Professor Rankine states, as the result of his own observation, that it is possible to shorten the bow to two-thirds of the length given by this formula, without materially increasing the resistance, but that it is very disadvantageous to shorten the afterbody.

In the 'Proceedings of the Institution of Civil Engineers,' vol. xxiii. (for 1864), p. 321, is a paper by Mr. G. H. Phipps, on the "Resistance of Bodies passing through the Water." Mr. Phipps considers that the total resistance may be subdivided as follows, into additive parts:—

Head-resistance—varying directly as the midship section, and inversely as the square of the projection ratio of the bow.

Stern-resistance—a similar function for the stern.

Friction-resistance—varying directly as the surface immersed.

Additional Head-resistance—an empirical correction assumed to be a function of the draught of water.

The sum of these resistances is then multiplied by the square of the velocity.

The paper was followed by a discussion in which most of the leading English writers on fluid resistance took part. The paper and discussion thus constitute a very fair *résumé* of the opinions then held on the subject in this country.

Mr. Phipps considers that the coefficient of friction of water on the outer surface of a vessel is less than on the inner surface of a pipe; and this is, to a certain extent, in accordance with the experiments of Darcy on the friction of water in pipes, which led to the conclusion that the coefficient of friction consists of two terms—one constant, and the other varying inversely as the diameter of the pipe.

Mr. John I. Thornycroft, C.E., in a paper read before the Institution of Naval Architects this year, and which will appear in their forthcoming volume of 'Transactions,' gives the following formula, the form of which is derived from experiments on the flow of water in pipes:—

$$\text{I. H. P.} = Vh \left\{ Sf \frac{3n}{2n+l} V^{1.7} + \phi S.C. \frac{n^{\frac{1}{3}}+3}{l^{\frac{1}{3}}+3} V^{3.7} \right\},$$

where S = the wetted surface, V = the velocity in knots, l = the length,

h, f, n, C are constants empirically determined:

$$\log h = 3.65450,$$

$$\log f = 2.10170,$$

$$\log C = 2.20041,$$

$$n = 380,$$

$$\phi S = f(\sin \theta)^{2.5} ds,$$

ds representing an elementary portion of the surface, S , and θ the angle which this portion of the surface makes with the line of motion. It will be noticed that the formula involves a large number of constants, more or less arbitrarily determined.

Professor Rankine, in a paper in the 'Transactions of the Institution of 1869.

Naval Architects' for 1861 (the substance of which is repeated in a treatise on 'Shipbuilding: Theoretical and Practical'), states that the processes amongst the particles of water through which resistance to the ship's motion may be caused indirectly may be thus enumerated:—

1. The distortion of the particles of water.
2. The production of currents.
3. The production of waves.
4. The production of frictional eddies.

The first cause he regards as having no appreciable effect on actual ships, although possibly sensible in small models. Of the second cause (the production of currents), Professor Rankine remarks that it "never acts upon a well-designed ship; for such a ship is so formed that the particles of water glide over her surface throughout its whole length, and are left behind her with no more motion than such as is unavoidably impressed upon them through adhesion and stiffness; and hence the failure of the earlier theories of the resistance of ships, which were founded on experiments made with flat plates, wedges, and blocks of unfair shapes."

Mr. Rankine then gives a detailed account of the waves which accompany a vessel driven at a speed greater than the limit to which she is properly adapted, showing that they diverge from the course of the vessel at an angle depending on the proportion in which their speed of advance is less than her speed, and thus carry off energy, which is lost; and he proceeds to state: "The conclusion to be drawn from these principles is, that for each vessel there is a certain limit of speed, below which the resistance due to the production of waves is insensible; and that as soon as that limit is exceeded, that resistance begins to act, and increases at a very rapid rate with the excess of speed. . . . Through the discoveries of Mr. Scott Russell, a vessel can be designed in which this kind of resistance shall be insensible up to a given limit of speed; and therefore the resistance due to waves has no sensible action on a well-formed ship." These remarks of course apply only to waves formed by the ship, and not to sea-waves which she may have to encounter.

"The resistance due to frictional eddies thus remains alone to be considered. That resistance is a combination of the direct and indirect effects of the adhesion between the skin of the ship and the particles of water which glide over it; which adhesion, together with the stiffness of the water, occasions the production of a vast number of small whirls or eddies in the layer of water immediately adjoining the ship's surface." Instead of assuming that the frictional resistance is simply proportional to the actual immersed surface, Mr. Rankine uses what he calls the *augmented surface*, which is obtained by multiplying each infinitesimal element of the surface by the cube of the ratio which the velocity of gliding of the water over that portion bears to the speed of the ship, and summing them. Let s be the actual surface, and q the velocity-ratio of gliding; then the augmented surface is $\int q^3 ds$; and if, further, V be the speed, g gravity, w the heaviness of water, and f the coefficient of friction, then

$$\text{Eddy-resistance} = V^2 f \frac{w}{2g} \int q^3 ds.$$

Taking the cubic foot as the unit, $\frac{w}{2g}$ does not differ much from unity for sea-water, and the formula thus reduces to $V^2 f \int q^3 ds$.

It is, of course, impossible to calculate $\int q^3 ds$ in detail for every ship; and

it therefore becomes necessary to find some auxiliary formula. In the 'Philosophical Transactions' for 1863, pp 134-37, Mr. Rankine has shown that the augmented surface of a trochoidal ribbon on a given base and of given breadth may be found by multiplying their product by the following coefficient of augmentation:—

$$1 + 4 (\sin \phi)^2 + (\sin \phi)^4,$$

in which ϕ is the angle which the inflexional tangent makes with the base. For a ship in which the stream-lines or tracks of the particles of water are trochoids, it would be a sufficient approximation to integrate,

$$\text{length} \times \frac{1}{2} \text{breadth} \times \{1 + 4 (\sin \phi)^2 + (\sin \phi)^4\}$$

with regard to the draught of water, considering both the angle ϕ and the half-breadths as variable elements to be determined from the drawings. Where the stream-lines are not trochoids, ϕ may be taken as the angle of greatest obliquity. But the theory has been only partially extended to three dimensions; and indeed if it were possible to do so, the mere introduction of a third variable would not meet the case, unless account were taken of the vertical displacement of the surface of the water consequent upon the uniformity of pressure at that surface.

The resistance determined by the calculation of the augmented surface includes in one quantity both the direct adhesive action of the water on the ship's skin, and the indirect action through increase of the pressure at the bow and diminution of the pressure at the stern.

For the coefficient of friction, Professor Rankine takes $f=0.0036$ for surfaces of clean painted iron. This is the constant part of the expression deduced by Professor Weisbach from experiments on the flow of water in pipes. The corresponding coefficient deduced from Darcy's experiments is 0.004.

The augmented surface in square feet, multiplied by the cube of the speed in knots, and divided by the I. H. P., gives *Rankine's coefficient of propulsion**. In good clean iron vessels this ranges about 20,000; while in H.M. Yacht 'Victoria and Albert' (copper sheathed) it reached 21,800. Its falling much below 20,000 is considered to indicate that there is some fault either in the ship or in her engines or propeller, or else that the vessel is driven at a speed for which she is not adapted.

Professor Rankine adds that "as for misshapen and ill-proportioned vessels, there does not exist any theory capable of giving their resistance by previous computation."

This, again, raises the question, What are *good* forms? According to Professor Rankine's theory, they are forms along which a particle of water can glide smoothly. Among these, as a particular case, Mr. Scott Russell's wave-lines appear to be included. But these are by no means the only ones which satisfy the problem of smooth gliding, or of stream-lines. Another method of constructing curves fulfilling this condition has been given by Mr. Rankine in a series of papers published respectively in the 'Philosophical Transactions' for 1863, p. 369, and in the 'Philosophical Magazine' for October 1864, and January 1865. Elementary descriptions of this method are given in the 'Engineer' of the 16th of October 1868, and in a treatise on 'Ship-building: Theoretical and Practical.' Their theory has not yet been carried very far; and when we have reference to three dimensions, it does not appear

* For examples of that coefficient, see the 'Civil Engineer and Architects' Journal' for October 1860, and the "Report of the Committee of the British Association on Steamship Performances," 1868.

that any specific mathematical form is to be preferred in respect of its total resistance to a long, fine, fair ship, either drawn or modelled by eye by a practised draughtsman or modeller.

A possible connexion between the resistance of ships and their depths of immersion has been pointed out by Mr. Rankine in some papers published in the 'Proceedings of the Royal Society' for 1868, p. 344, in the 'Reports of the British Association' for 1868, in the 'Transactions of the Institution of Naval Architects' for 1868, and in the 'Engineer' of the 28th August and 30th October, 1868. He shows from theory, corroborated by his own observations, and by those of Mr. John Inglis, junior, that every ship is accompanied by waves, whose velocity of advance is $\sqrt{gk}$, g being gravity, and k the mean depth of immersion, found by dividing the displacement by the area of water-section. So long as the speed does not exceed $\sqrt{gk}$, these waves cannot produce any additional resistance; but when the speed exceeds that limit, the waves are made to diverge from the ship at the angle whose cosine is $\frac{\sqrt{gk}}{\text{speed}}$, and thus to carry away energy, like the other diverging waves previously mentioned.

The form of the midship section does not appear to exercise any influence on the resistance to propulsion in still water, except so far as it affects the extent of wetted surface exposed to the action of the water. If the wet girth and the breadth at the water-line be given, the form of greatest area will be a segment of a circle; but this will not be the solution of the question which usually presents itself, namely, given the breadth and the draught required, the form for which the ratio of area to surface shall be the greatest possible. In the particular case in which the draught is half the breadth, it is easily seen that the ratio of area to girth is the same for a semicircular as for a rectangular section, and therefore that the solution lies between these extreme cases. It does not appear that the general problem has yet been solved, and perhaps, as the really practical problem relates to the ship and not to the midship section, it is of secondary interest. A restricted solution has been given by Mr. James Robert Napier in a paper read before the Glasgow Philosophical Society, and reprinted in the 'Mechanics' Magazine' for 24th April, 1863, vol. ix. p. 311, and in the 'Engineer' for 1st May, 1863, vol. xv. p. 245.

The best ratio for good propulsion of length to breadth and draught, even when it is assumed that the length exceeds Scott Russell's limit, is not yet known. This is not perhaps of practical importance, inasmuch as considerations of economy, capacity, and handiness generally settle these proportions, without much reference to a theoretical maximum of efficient propulsion. But the extent to which an increase of breadth or depth, leaving other things unaltered, affects the propulsion itself can hardly be regarded as within our settled knowledge.

The resistance of the air to a ship's hull is not a point to be neglected in practice or in experiment; but it is not one which we propose to discuss here.

The above contains an abstract of nearly all that is known concerning the TOTAL RESISTANCE of a ship in smooth and deep water. We do not consider it necessary in this Report to enter into the question of the increased resistances due to shallow water, narrow channels, or a rough sea. We may sum up the result in the broad statement that there exists no generally recognized theory or rule for calculating the resistance of a ship. Many such rules

have been put forth; but they do not agree in their form or in their result, and the credit of each consequently rests, as a practical matter, on the reputation of its author.

Resistance considered in Detail.

It cannot be said that our knowledge of the detailed phenomena which accompany the motion of a floating body through the water extends far below the surface of the liquid. Meanwhile the following things appear to be known.

For any vessel driven through the water by any power which does not react on the fluid there must be a certain movement of the surrounding liquid, chiefly in the direction of the vessel's motion, which shall be sufficient to absorb the work done by the propelling force; for this is really nothing else than the work done by the power in overcoming the resistance. Much of this is masked by oscillatory movement. Now the setting up of an oscillation involves an expenditure of work; but the maintenance of the oscillation, once established, is independent of the force which caused it, to just the same extent that it takes work to set a pendulum swinging, but once set going, the continuance does not depend on the starting force. It follows that making a wave takes up propelling work; but that a wave once started maintains itself, or dies out, as the case may be, independently of the propeller, which it can only affect by getting in its way.

In a vessel of good form thrust through a fluid, we first meet with a head-pressure which relieves itself by the formation of a head swell, which disperses itself all round if time be allowed for it, either by the sharpness of the vessel's entrance, or by a slow rate of advance. This fixes a limit of speed, which cannot be advantageously exceeded, dependent on the length of entrance as well as on its form,—on the length alone if the form fulfil certain conditions. If the vessel be pushed beyond the speed of dispersion of this wave, it has to be pushed up hill at a loss of useful work.

The frictional resistance of the surface of the ship also carries a stream of water in the direction of the ship's motion. In fact, nearly the whole work of friction is expended on producing this stream, which forms a part of the ship's wake.

The necessity of filling up the vacuum which would otherwise be left in rear of the ship also produces a following stream, accompanied with waves.

In vessels driven at a speed beyond what is suited to their form and dimensions, there are also supernumerary waves, an account of which will be found in Professor Rankine's writings already referred to.

In vessels of unfair form there will further be violent eddies or whirlpools, as well as extra waves. Seeing that it takes an expenditure of work to make these, it is clear that least resistance means least disturbance. In reality very little is known about these eddies. Their surface-action has been observed, and may easily be seen in dirty water, with froth especially; but their extent in depth, and their amplitude as the depth increases, are utterly unknown; and the other phenomena are not sufficiently well understood to admit of the effect of these being got at by exhaustion, that is to say, by being equated to the unexplained residue from the effects of the other known causes. Very little, again, is known about the direction in which the replacement aft takes place. The water may of course pour in either laterally or from behind, or it may well up from underneath as a wave. More or less, it probably does all three, and the proportion in which it does each is among the things which neither experiment nor theory has as yet revealed.

Theoretically it is of no importance whether we consider the ship in motion and the water at rest, or the ship at rest and the water in motion in an opposite direction. Practically the conditions are modified by the consideration that a stream of water almost always has a sloping surface, in which case a resolved part of gravity is one of the active forces*. Besides this, streams useful for experiment are restricted in depth and width, and the conditions of narrow and shallow channels introduce foreign considerations of a very complicated character.

Propulsion.

We do not consider it advisable in the present Report to enter into the question of propellers, except so far as may be necessary to the choice of experiments.

All propellers, except sails, tow-ropes, and punt-poles, do their work by the reaction arising from their driving a stream of water in the opposite direction to the ship's motion, or to their stopping or reversing streams already flowing in that direction. This is the case with oars, paddle-wheels, screws, and water-jets alike. But while they thus have one principal action in common, they are wholly different in their detailed effect upon the currents and waves which accompany the ship, and in the way in which these currents and waves react upon them. Thus the oars of a row-boat send two streams aft, at such a distance from the sides of the boat as to interfere very little with, and to be very little interfered with by, the waves and eddies due to the boat's motion. In the screw-propeller, on the other hand, a large proportion of the wake current is either stopped or reversed by the action of the screw, which also interferes with, and is itself reacted upon by, the wave of replacement. These interferences are so large in amount as not unfrequently to mask the whole of the *slip*, from the reaction of which the propulsion is obtained, giving rise to the phenomenon of *apparent negative slip*. For a theoretical account of what is supposed to take place under these circumstances, we refer to the following Papers in the 'Transactions of the Institution of Naval Architects,' and the discussions which took place upon them:—

Rankine, "On the Mechanical Principles of the Action of Propellers."

Froude, "Note on the above Paper," vol. vi. for 1865, p. 13 *et seq.*

Reed, "On Cases of Apparent Negative Slip," vol. vii. for 1866, p. 114 *et seq.*

Rankine, "On Apparent Negative Slip."

Froude, On the same.

Rigg, "On the Relations of the Screw to its Reverse Currents," vol. viii. for 1867, p. 68 *et seq.*

Rigg, "On the Reverse Currents and Slip of Screw-propellers," vol. ix. for 1868, p. 184.

See also Bourne, 'On the Screw-propeller,' second edition, chap. iii., and Rankine, 'Shipbuilding: Theoretical and Practical,' pp. 88, 89, 247, and 259.

We consider it to be beyond doubt that the theoretical investigations of this part of the subject have been extended in advance of the point at which fresh experimental foundations ought to be laid for them.

* This remark is due to Bourgois. See his Memoir, *sup. cit.* p. 3.

Former Experiments on Resistance.

The first important experiments were those made by Bossut, Condorcet, and D'Alembert, by direction of Turgot. The results were published as a separate work in 1777, and a very full abstract of them is given by Bossut in his 'Hydrodynamique.' The chief results are summarized by Bossut as follows :—

That the resistance of the same body at different speeds, whatever be its shape, varies very nearly as the square of the speed.

That the direct head-resistance of a plane surface is sensibly proportional, at the same speed, to the area of the surface.

That the measure of the direct resistance of a plane surface is the weight of a fluid column which has that surface for its base, and whose height is that due to the velocity.

That the resistance to oblique motion, other things being alike, does not diminish by a law at all approaching that of the squares of the sines of angles of incidence ; so that for sharp entrances, at least, the former theory must be completely abandoned.

Mr. Scott Russell has remarked that between certain limits the observed resistances of wedge-bows could be represented with a close degree of approximation by a formula of the form

$$R=K\left(\frac{\pi}{2\pi-\epsilon}\right)^2,$$

where K is a constant, π stands for 180° , and ϵ is the angle of the wedge, which is supposed to be of not less than 12° , and not more than 144° . See his 'Naval Architecture,' p. 168, and 'Transactions of Civil Engineers,' vol. xxiii. p. 346.

The next experiments of importance are those of De Chapman, published in his 'Architectura Navalis Mercatoria.' The result of these has already been mentioned. He performed some fresh experiments at Carlscrona, in 1795, which seemed to lead to somewhat different conclusions. See Inman's translation of De Chapman, pp. 41 and 257.

We then come to Beautfoy's experiments in the Greenland Dock from 1794-98. This enormous series of experiments can only be regarded as establishing very few facts, among which we may mention :—

That the resistance to oblique surfaces does not vary as the sine squared of the angle of incidence.

That for *unfair* bodies, such as he experimented upon, the resistance increases faster than the square of the velocity.

That increase of length, within certain limits, has a tendency to decrease resistance.

That friction of the wetted surface enters largely into the resistance.

That friction of the wetted surface appeared to increase in a ratio somewhat less than that of the velocity squared,—between $v^{1.7}$ and $v^{1.8}$.

He also arrives at the conclusion that bodies immersed to a depth of 6 feet experience less resistance than at the surface ; but in the case of an iron plane towed flatwise, he found that resistance increased with the depression.

The whole of these experiments lose much of their value from having been tried on small models, and on bodies which are not ship-shape.

The 'Philosophical Transactions' for 1828 contain an account of experiments performed by Mr. James Walker in the East-India Import Dock. A

bluff-bowed boat was towed across the dock by a rope and winch, worked by labourers, the rope being fast to a spring weighing-machine on board the boat. The boats tried were of somewhat bluff form, and it was found that the resistance varied only roughly as the velocity squared, increasing faster than that at high speeds. The drawings of the boats are not given with all the detail that could be desired, nor is the condition of their surface minutely described; but the experiment was in the right direction, being upon actual boats meant for use, and of a size far exceeding the models of previous experimenters.

Some experiments by Mr. Colthurst, both on the forms of floating bodies as affecting their resistance to motion, and on the friction of wetted surfaces, are given at p. 339 of vol. xxiii. of the 'Civil Engineers' Transactions.'

We also refer to the Report of the Committee appointed by the British Association upon the comparative resistance of bodies wholly and partially immersed (B. A. Reports, vol. for 1866, p. 148). The Committee decided to print the observed facts without any deductions. It is not necessary to the purposes of this Report that we should discuss them. We have already alluded to the difficulty which they indicate as being felt with respect to the way in which the water of replacement flows in at the stern.

We will next refer to the experiments of Captain Bourgois, which were begun at Indret, in 1844. He first had several boats from 22 to 25 feet long towed by the 'Pelican' steamer, then under his orders, and later a small merchant schooner of a little over 60 feet long, and afterwards the 'Fabert,' a brig 98 feet long. These vessels were simply towed, and their actual resistances measured with a traction-dynamometer. Similar experiments have also been tried in France with the screw-steamer 'Sphinx,' 109 feet long; with the screw despatch-boat 'Marceau,' 131 feet long (with its screw upon deck), and with the 74-gun ship 'Duperré,' 180 feet long, built by Sané. Probably nothing could be better than the experiments thus made, and it is from these that M. Bourgois has derived the coefficients of the formulæ which he has given. But, unfortunately, the particulars of the ships experimented upon are not given in great detail, nor are their drawings published. The only particulars given are the length and breadth on the water-line, the draught, and the area of midship-section immersed, but without wet surface, or even displacement.

M. Bourgois's memoir has no date; but it is evidently later than 1853, since he mentions that as the date of the experiment. It also contains some results of trials of propellers set to work against a dynamometer with the vessel made fast, and some trials depending upon the measurement of the power exerted by the engine. But we do not propose to discuss the trials on steam-ship performance. Not only is this the work of another Committee, but, inasmuch as they introduce the uncertain effects of the engine and propeller, they fail to give any accurate account of the resistance of the water.

In the earlier history of the subject, it was supposed that models would most aptly represent ships at the same speed both for the ship and the model. The experiments at the East-India Import Dock in 1827 and 1828 seem to show a dissatisfaction with the results of small models; and some time later, M. Réech, the Director of the Ecole d'Application du Génie Maritime in France, pointed out that models of different sizes intended for comparison should be made to move at velocities varying as the square roots of their lineal dimensions. In this case the actual resistances would vary as the

cube of the lineal dimensions. This would follow from the theory of the resistance of submerged bodies, on the supposition that the resistance varies as the square of the speed. If, again, we consider Mr. Scott Russell's theory of the length of ships (that their extreme speed should not exceed that of an oscillating wave, bearing a definite ratio of length to that of the ship), we arrive at the same conclusion, the length of the wave varying as the velocity squared.

Proposed Experiments.

The experiments upon resistance which we consider most important to be made are these :—

That a ship of considerable size and fine form should be carefully selected ; a screw steam-ship, with a screw capable of being lifted, with a clear deck, offering no unnecessary resistance to the air, and with little or no rigging.

That her form should be carefully measured in dock (her lines taken off, as it is technically called), and sight-marks carefully laid down, so as to ascertain whether she deforms in any way when afloat.

That she should be towed at various speeds, from the slowest that can be rated to the fastest that can be obtained ; and that the resistance should be ascertained by a traction-dynamometer, self-recording.

That the place selected for the experiments should be a deep inland water, free from ground-swell, and such that the speed of the ship can be observed from the land as well as from the vessel. The water also should be clear enough to admit of being seen through to a considerable depth. The place, if tidal at all, should be free from cross tides or irregular currents. These conditions, it is believed, may be found both in Norway and on the west coast of Scotland.

Careful observations should also be made with a view to ascertain the direction and velocity of the local currents caused by the ship's motion. What these should be will demand careful consideration, having regard both to the ship and to the place selected, and to the *personnel* of the observers.

The same remarks will apply to the precautions necessary to prevent interference by the currents thrown back by the towing-vessel or vessels, and to eliminate other sources of error. It is of especial importance that the ship which is being towed should be kept clear of the wake of the towing-vessel or vessels. It might be necessary for this purpose to have two tug-boats with hawsers meeting at an angle in the form of the letter Y.

It is desirable that these experiments should be performed with at least two vessels considerably differing both in size and proportions, and, for each of them, with different condition as regards smoothness of surface.

A third class of experiments should also be made to determine the rate of retardation of a vessel which has been made to attain a certain velocity, and then (the propelling-power suddenly ceasing to act upon her) is allowed to come gradually to rest through the resistance of the water.

It would be desirable that the same vessels (and as nearly as possible under similar conditions of draught and trim) should be made use of for trials of propulsion, and that in these, again, a dynamometer should be interposed between the engine and the propeller ; and in this case also the local currents and waves due to the joint disturbance of ship and propeller should be observed.

We consider that experiments of the kinds which we have proposed have now become necessary, not only to the theory of resistance, but also to the practical calculations of the effect of steering- and propelling-apparatus, and

incidentally to the design of these and to the apportionment of engine-power and driving-speed.

Such experiments are quite beyond the means of any body but the Government of a naval power in time of peace, possessing ships which must be exercised with their crews and staff of officers. There would of course be extra expense attending such trials; but this expense is in no way commensurate with that of building experimental vessels, or arriving tentatively at the suitable forms and positions for propellers.

We therefore recommend that the Council of the British Association should authorize a deputation to apply to the Admiralty to provide for such a set of experiments in the course of the summer of 1870; also, that the Council should appoint a Committee, consisting of three Members of the Association, to confer with officers of the Admiralty respecting the detail of the experiments, and that the Admiralty should be requested to give an opportunity to the Members of that Committee of taking a share in the observations, in order that they may be enabled to make an independent report upon the results.

ROLLING OF SHIPS.

Stability and Free Oscillation.

The statical stability of a ship in still water depends upon two equations and an inequality.

Its weight must equal that of the fluid it displaces, or it will adjust itself by changing its water-line. This involves a first equation.

The centre of gravity of the displaced water must be in the same vertical line with the centre of weights, or there will be a couple which will produce rotation; after which the ship will take up a fresh position. This involves a second equation.

In case of a small angular displacement, the centre of gravity of the displaced water (or CENTRE OF BUOYANCY) must move out faster than the centre of weights; otherwise, on the slightest derangement, there will be an upsetting couple, that is to say, the equilibrium is unstable. This involves an inequality.

The arm of the couple is the horizontal distance between the centres of weight and buoyancy. The moment of the couple is the product of this into the weight, or, what is the same thing, the displacement of the ship. If the centre of buoyancy moves out faster than the centre of weight as the ship heels, there is a righting couple; if not, there is an upsetting couple, which tends to bring the ship to some new position of equilibrium.

If we consider a vessel having a plane of symmetry like that in which the masts, stern, stern-post, and keel of ordinary ships lie, and rolling transversely, we gain much in geometrical simplicity, and also in simplicity of language. We are enabled to deal with the mechanical questions by means of plane geometry, and we are still able to extend them, when necessary, by the ordinary rules of the composition of motion. For this purpose we have only to consider the axis of motion as parallel to the plane of symmetry and to the water-section. The statical stability, as already remarked, is measured by the weight, and by the horizontal distance between the centres of weight and buoyancy. But when these coincide in horizontal position, as they do when there is equilibrium, we are driven to some other measure in order to avoid indeterminateness at the limit. For this purpose we avail ourselves of the point at which the vertical line through the centre of buoyancy strikes

the plane of symmetry, or *middle-line plane*, as it is technically called. The limiting position of this intersection, when the angular deviation is indefinitely small, is called the METACENTRE. This metacentre is the critical point below which, if the centre of weight be kept, there will be stable equilibrium.

It is shown in books on hydrostatics that if a floating body receive a *small* inclination, the two water-sections intersect in a line passing through the centre of gravity of each, and also that the line passing through two successive centres of buoyancy tends to parallelism with the water-section. It follows that the stability of a ship, statically considered, may be measured by the statical stability of a solid, whose centre of gravity coincides with that of the ship, but whose surface, instead of floating in water, rests on a horizontal table. This representative surface is the surface formed by the centres of buoyancy of the ship at different inclinations. The metacentre of the ship is then the centre of greatest or of least curvature of this representative surface, called the *surface of buoyancy*, according to whether we consider transverse rolling or longitudinal pitching.

When we pass from statics to dynamics, the righting or upsetting force simply represents an acceleration. But if the ship be considered as concentrated at its centre of gravity (in disregard of the actual distribution of weights in respect of inertia), the same geometrical considerations hold, and the space through which the centre of gravity rises or falls as the surface of buoyancy rolls is called the measure of *dynamical stability**. It is simply proportional to the integral of the statical stability taken with reference to the angle of inclination. Its product into the displacement gives the *mechanical work* required to heel the ship, considered as concentrated at its centre of gravity, to a given angle. An example of its use is in the solution of the problem of finding how much a ship would lie over to a sudden gust, strong enough, if it came on gradually, to heel the ship to a given angle. The rough solution is that she would lie over to double the angle of the statical stability; and this remark is of importance in judging of the safe limits of a ship's stability. This solution, it is to be observed, takes no account of the moment of inertia of the ship about its centre of gravity, and very little account of external form.

Experiment and theory both go to prove that the time in which a ship performs a complete double oscillation varies but very little, whether the amplitude of the oscillation be small or large. Hence every ship has its equivalent pendulum. If k be the radius of gyration of the ship, μ the distance between the metacentre and the centre of gravity, the length of the equivalent pendulum is $\frac{k^2}{\mu}$, the periodic time† is $2 \frac{\pi k}{\sqrt{g \mu}}$, and the greatest angular

velocity is $\frac{2 \sqrt{g \mu}}{k} \sin \frac{1}{2} \theta$, where θ is the amplitude, or departure from the vertical; but the approximation in this last formula is much less than in that for the time.

Dupin has shown that the free rolling of a ship, regarded without refer-

* The true dynamical stability is the actual work done in heeling; but the words are ordinarily used in the sense stated in the text.

† The time here used is that of a double oscillation; i. e. the time which elapses between the bob of the pendulum passing the lowest point twice in the same direction. There is very often confusion between double and single oscillations, both with analysts and in the records of experiments.

ence to the disturbance or resistance of the water, is analogous to the free rolling and sliding, on a smooth plane, of the surface which is the envelope of its planes of flotation, the centre of gravity, the upward pressure of the fluid, and the moment of inertia being supposed to remain unaltered. But although this statement reads simply enough, the expressions for the time and the period, which result from it, are exceedingly complex. An investigation of it, subject to the sole restriction that the transverse section of the surface enveloping the planes of flotation shall be circular, has been given by Canon Moseley in the 'Philosophical Transactions' for 1850, p. 626, and is reprinted in his 'Engineering and Architecture.' The resulting expression depends upon a hyperelliptic integral. But we are without evidence as to how far the restriction is fulfilled by ordinary ships; and we do not find reason for supposing that the variation of the radius of curvature, which is thus taken as constant, has ever been practically investigated. There is, however, no difficulty in extending the formula to the general case; but it does not appear that the integration can be effected without introducing restrictions. At any rate the value of the integral has not yet been traced, except for small oscillations, when it reduces to the one previously given. There is a reduction in some particular cases*, and notably in the case of isochronous ships. Professor Rankine† has shown that the condition of isochronism is that the curve of buoyancy should be the second involute of a circle described about the centre of gravity.

It does not appear that the arithmetical consequences of the variation of the law connecting time and angular velocity in unresisted free rolling have ever been worked out. It would be a very laborious business; and we shall see by-and-by that it is not the chief problem.

* Let k be the radius of gyration, λ the height of the metacentre above the centre of buoyancy, H_1 and H_2 the depths of the centres of gravity and buoyancy— all taken for the upright position. Also let θ be the inclination and θ_1 the extreme, and ρ the height of the centre of curvature above the actual plane of flotation. Then Canon Moseley's formula gives for the periodic time of the double oscillation

$$\sqrt{\frac{2}{g}} \int_{-\theta_1}^{+\theta_1} d\theta \sqrt{\frac{k^2 + (H_1 + \rho)^2 \sin^2 \theta}{\{H_1 - H_2 + \frac{1}{2}\lambda} (\cos \theta + \cos \theta_1)\} (\cos \theta - \cos \theta_1)}}.$$

It will be observed that $(H_1 + \rho) \sin \theta$ is nothing but the horizontal distance between the centre of gravity of the ship, and that of the plane of flotation; or, in other words, the perpendicular from the centre of gravity on the normal to the flotation-envelope. It seems, at the same time, simpler and more general to use this (which we may call ν), instead of considering the curvature. We thus get for the periodic time

$$\sqrt{\frac{2}{g}} \int_{-\theta_1}^{+\theta_1} d\theta \sqrt{\frac{k^2 + \nu^2}{\{H_1 - H_2 + \frac{1}{2}\lambda} (\cos \theta + \cos \theta_1)\} (\cos \theta - \cos \theta_1)}}.$$

Now, if ν be constant, that is to say, if the flotation-envelope be the involute of a circle described round the centre of gravity of the ship, this reduces to a complete elliptic integral of the first kind; but the solution is not mechanical unless $\nu=0$, or the flotation-envelope reduces to a point. When, moreover, the centres of gravity and buoyancy coincide, $H_1 - H_2$ vanishes, and the integral may be at once transformed to its regular expression by writing $\sin \theta = \sin \theta_1 \sin \phi$. We then get for the periodic time

$$\frac{4\sqrt{k^2 + \nu^2}}{\sqrt{\lambda g}} \int_0^{\pi} \frac{d\phi}{\sqrt{1 - \sin^2 \theta_1 \sin^2 \phi}}.$$

The time at any moment is got by integrating from $-\theta_1$ to any value of θ instead of to $+\theta_1$.—C. W. M.

† See Trans. I. N. A. vol. v. for 1864, p. 34. See also Froude "On Isochronism of Oscillation in Ships," Trans. I. N. A. vol. iv. for 1863, p. 211.

Reverting to the approximate formulæ for small oscillations—

$$\text{periodic time} = 2 \sqrt{\frac{\pi k}{g\mu}} = 2t, \text{ suppose ;}$$

$$\begin{aligned} \text{greatest angular velocity} &= \frac{2\sqrt{g\mu}}{k} \sin \frac{1}{2} \theta, \\ &= \frac{2\pi}{t} \sin \frac{1}{2} \theta, \end{aligned}$$

we see that the periodic time of the oscillation varies directly as the radius of gyration, and inversely as the square root of the metacentric height. This teaches us how to regulate the periodic time of a ship, either in settling her design, or in the distribution of her weights. We see, for instance, that a vessel with a rising floor and flaring sides tends to quick rolling, by having a high metacentre; that a cargo of railway-bars has the same effect, by bringing down the centre of gravity; and that running-in the guns and sending down the masts has a similar tendency, by decreasing the radius of gyration. The expression for the greatest angular velocity has been sometimes interpreted as indicating that quick rollers roll through large angles. The fact appears to be experimentally true, but its inference from this formula involves reasoning in a circle. The formula only shows that for the same amplitude the greatest angular velocity varies inversely as the time; but this tells us nothing about the amplitude, while the formula itself is obtained on the supposition that the amplitude is small.

The position of the ship's centre of gravity and the length of the radius of gyration cannot, practically, be obtained by calculation. The centre of gravity is generally found by shifting some known weights through known distances, and observing the angular motion. The displacement and metacentre are of course known by calculation, and the problem is then the same as if the ship were suspended from her metacentre*. The radius of gyration is found by observing the time of a small oscillation in still water, and then eliminating the effect of resistance†.

As the metacentre depends upon the moment of inertia of the plane of flotation, it is different for pitching from what it is for rolling, and so for any intermediate position‡. Practically, the metacentre for rolling varies from 0 to 20 feet (as an extreme limit) above the water-line, while that for pitching is from 70 to 400 or more feet high. The moment of inertia of the ship also varies greatly with the direction of the axis about which it is taken.

Free Rolling in a Resisting Medium.

The experiments of Messrs. Fincham and Rawson, undertaken at the suggestion of Canon Mosley§, led to the conclusion that for vessels of semi-circular section in which the disturbance of the water is the least possible,

* The method, with an account of some experimental determinations on several of H.M.'s ships, will be found in the Trans. Nav. Arch. vol. i. p. 39. See also v. p. 1; vi. p. 1; vii. p. 205.

† As to this, see Mr. Rankine's Note in Trans. I. N. A. vol. v. pp. 31, 32.

‡ See Dupin, 'Applications de Géométrie.' He shows that the metacentric heights for rolling and pitching are, in fact, only the two principal radii of curvature of the surface of centres of buoyancy; and hence the metacentres for intermediate positions may be found by the help of the ellipse of curvature.

§ See Phil. Trans. for 1850, and Mosley's 'Engineering and Architecture,' pp. 616, 617.

the dynamical stability found by experiment differed very little from that derived from the rise and fall of the centre of gravity; but in the case of a model of triangular section, the stability found by experiment was in defect. In the semicircular model the extreme inclination produced by the sudden application of the force was, with a fair degree of approximation, double that due to its static effect. With the triangular model the extreme was less than double the static inclination. This is nothing more than might be expected from the disturbance of the water which would be set up by the angular model, and which would, of course, take up part of the work. But this experimental confirmation of theory is highly satisfactory, and, however we may now look back upon the matter, it really upholds the experiments that the confirmation of our theories rest.

In a resisting medium, the amplitude of the oscillation is very greatly affected, but the periodic time undergoes very slight change; but the period is altered to a slight extent. On this subject we refer, first, to the account given by Poisson, Stokes, and other writers on mechanical oscillations; the oscillation of a pendulum in air; secondly, to Mr. Fraude's observations on a pendulum oscillating in water; and thirdly, to Professor Rankine's paper on keel-resistance, in which the increase of damping is ascribed to a certain hypothesis.

Bessel and Poisson have pointed out that the virtual loss of weight due to oscillation in a resisting medium is greater than that due to the mere immersion. Mr. Moseley makes the same remark with reference to the rolling of ships.

Professor Rankine has investigated the effect of the steady rotation of a keel on the rolling in smooth water, on the assumption that the moment of the righting couple is simply proportional to the inclination, and also that the moment of resistance to rolling, caused by the action of the water on the keel and floor, is proportional to the angular velocity. He finds that the periodic time is altered from

$$\frac{2\pi k}{\sqrt{g\mu}} \text{ to } \frac{2\pi k}{\sqrt{g\mu} \sqrt{1 - \frac{r^2 e^2}{4\mu k^2}}}$$

where e is a constant depending on the moment of the resistance; so that

$$e = \frac{\text{moment of resistance of water}}{\text{displacement} \times \text{angular velocity}},$$

the effect of the resistance thus lengthening the periodic time in the ratio

* Trans. Inst. Nav. Arch. vol. iii. p. 31. Mr. Fraude has there shown that when a pendulum or ship performs synchronous oscillations in a medium the resistance of which varies as the square of the velocity, the amplitudes of the successive oscillations, as reduced by resistance, will form successive ordinates of a curve, which approaches with a great degree of exactness, to an equilateral hyperbola, referred to one of its asymptotes, equal periods of the oscillations being represented by successive equal increments of the abscissa.

The experiments with a pendulum as exhibited in the diagram (plate 2 of the volume referred to) accord very closely with the law which may be thus expressed:—If θ_0 be the initial amplitude, and θ_n that of the n th oscillation, then that at the end of any other, say n th will be

$$\theta_n = \left(\frac{m - n}{m + n} \right) \theta_0 + n \theta_0$$

† Trans. Inst. Nav. Arch. vol. v. pp. 30, 31.

‡ Ibid.

proportion as if the inertia of the rolling mass were increased in the ratio of unity to

$$1 - \frac{g c^2}{4 \mu k^2},$$

and periodic rolling in smooth water becoming impossible when $g c^2$ is equal to or greater than $4 \mu k^2$.

Of Easy and Uneasy Ships.

There is much vagueness in the use of these terms. They are generally applied promiscuously to the practical hindrance caused by motion to the persons engaged in working or manœuvring the ship, to the inconvenience felt by passengers, to the straining of a ship's structure, or the tendency to shift her cargo, or to break away half-fastened weights, like boats or guns.

These all appear to depend in varying proportions on the following exact data:—

The extent or amplitude of angular motion.

The rapidity of angular motion.

The acceleration of linear motion.

But the rapidity of linear motion and the angular acceleration (except so far as this affects bending stress, or as it involves linear acceleration at a distance from the instantaneous axis) do not appear to have much practical influence.

In still water the only motion which is sufficiently great to cause inconvenience is that of rolling. Rolling sometimes produces as secondary phenomena both pitching and dipping; but neither of these are sufficient in extent, in still water, to produce inconvenience. The rolling, however, may be considerable, especially in the case of a ship going unsteadily before the wind. But if the water itself be oscillating, even moderately, or if there be a gusty wind, then a synchronism between any two of the five movements—the wind, the waves, the rolling, the pitching, or the dipping*—or even (to a lesser extent) their concord at regular intervals—may cause them to enhance the effects one of another to such an extent as to become inconvenient, and in certain cases dangerous. In the case of a thoroughly uneasy ship in the most unfavourable circumstances, the axis of angular motion may assume any and every position, and the linear acceleration may take all conceivable directions; but although any particular point may describe the most irregular curves, both in form and speed, relatively to the vessel's course, yet the chief source of practical danger in open water depends upon the accumulation of motion arising from synchronism.

It appears to have been generally observed that vessels which have a short period of rolling, also roll through large angles. In this way the uneasiness of the rolling undergoes a double increase as the period diminishes. Further and more exact experiment is required before we can say how far it is connected by synchronism with wave motion, or whether it is an independent phenomenon. Our present theories do not show it to be a necessary consequence of rolling in smooth water.

Waves.

We do not consider it necessary to go into a formal discussion of this subject. As regards the behaviour of ships, it is quite sufficient to assume that

* Dipping is the name given to the vertical oscillation of the ship as a whole relatively to the surface of the water.

the profile of a simple wave is trochoidal, and that the particles of water move in circles in a vertical plane, at right angles to the ridges and valleys of the waves. The consequences of this motion are briefly as follows, on the assumption that the depth of water is unlimited.

The diameter of the circle in which a surface particle moves is the height of the wave from hollow to crest. Particles which in still water would be at a lower level, describe smaller circles in the same period. A horizontal plane (in the still water) is thus converted into a wave-surface of the same period, but of reduced amplitude of oscillation (*). The velocity of the particles (and on this depends the *impact* of a wave) is simply the circumference of one of these circles divided by the periodic time.

If we consider a column of particles which is vertical in still water, that column oscillates in wave-water like corn-stalks in a *mead* of wind, and it also oscillates vertically. But it always slopes *towards* the crest of the wave, and the obliquity thus induced goes to enhance that due to the wave's period; so that if we regard the profile of a wave, a small portion of water, rectangular when still, undergoes a double deformation, the horizontal surfaces following the wave-slope, and the vertical surfaces being deflected towards the crest, both causes tending to increase the angular deformation instead of to preserve rectangularity.

The crest of the wave being sharper than the hollow, and the quantity of water invariable, the horizontal plane which lies halfway between valley and crest is higher than the mean, or still-water, level; and its elevation has been shown to be equal to the height due to the velocity of revolution of the particles.

Considered as trochoids, the wave profiles are traced by a point within a circle rolling *under* a horizontal line. The line midway between valley and crest is the line of centres.

The particles of water above the line of centres are moving forward, as regards the direction of advance of the wave; those below that line back-wards. The particles in the front face of the wave are rising, and those in the rear-face falling.

The wave whose period is $\frac{1}{n}$ th of a second has a length of $\lambda = \frac{g}{2\pi n^2}$, whence we find the number of waves to a second to be $n = \sqrt{\frac{g}{2\pi\lambda}}$. The velocity of wave-propagation, that is to say, of the apparent advance of the wave in a deep sea, is $n\lambda = \sqrt{\frac{g\lambda}{2\pi}}$. In other words, the speed of the wave-crest varies as the periodic time, and the length of the wave varies as their product, or as the square of either.

The vertical disturbance of a particle whose depth in still water would be h is

$$hk = hc - \frac{2\pi}{\lambda}$$

h being the height of the surface-wave.

* Drawings of the structure of a trochoidal wave will be found in the British Association Reports for 1844, plate 56; Trans. L. N. A. vol. i. for 1860, plate 7, vol. iii. for 1862, plate 3, vol. iv. for 1863, plate 10, and vol. vi. for 1865, plate 10; 'Shipbuilding: Theoretical and Practical,' Rankine, p. 69; Scott Russell, 'Naval Architecture' plate 117.

No wave can be sharper than a cycloidal wave; for if the trochoid were looped, the particles in the loop would be unsupported. When the wave form tends to pass the cycloid, it must break.

The extreme observed height of ocean-waves appears to be about 40 feet, and the greatest observed length 600 feet; these would have a periodic time of 11 seconds (roughly); their crest would advance at a rate of 33 knots an hour, and the velocity of the surface-particles would be about 11·4 feet per second. In short waves of the same height the particles of water move faster, in the inverse ratio of the period; but the mass of moving water at the crest of the longer wave is the greater in the ratio of

$$\lambda - \pi h : \lambda^1 - \pi h,$$

where λ and λ^1 are the lengths, and h the height. If, therefore, the above-mentioned wave were shortened to 200 feet, the surface-particles would be moving at a rate of 20 feet a second, while the mass of water in the crest would be about one-sixth. From such data it is easy to infer both the destructive effect of impact from the top of a wave, and the relative quantity of water which a ship would take on board in shipping a sea.

The front and rear of a trochoidal wave are exactly similar. Observation, as well as theory, shows that this is true to an extent not commonly believed for ordinary waves. The exceptions are, when the wind is sufficient to push the tops of the waves at extra speed, and when the water shoals rapidly. But even here the relative steepness of the advancing face is exaggerated by most observers. Until a wave is about to break, the actual difference of slope remains very small.

It should be borne in mind that circular orbits and trochoidal wave-surfaces are only approximations, although near enough to the truth for purposes connected with the rolling of ships. In particular, it appears both from theory and observation that there is almost always some progressive motion combined with the orbital motion; and also that waves begin to break long before their crests attain a form so sharp as that of the cusped cycloid, the two slopes at the crest of a breaking wave cutting each other at right angles, or nearly so*.

The ordinary wave of a rough sea is usually an aggregate of waves of different period, and not unfrequently of different direction. For rough purposes, it is sufficient to draw each system of waves separately and add their corresponding ordinates, to get the resulting surface. This can hardly be relied upon in extreme cases; and, in any case, the motion of each particle is not according to any one or more wave-systems separately, but it is a motion compounded of what would be due to each separately if the others were not.

Oscillations of a Ship among Waves.

A Treatise on 'Shipbuilding: Theoretical and Practical†,' edited by Professor Rankine, contains, in a very clear and condensed form, a *résumé* of nearly all that was known on this subject up to 1864 inclusive. The following abstract is chiefly taken from that work:—

It is to be observed that what follows relates to the composition of the ship's oscillation with that of a simple trochoidal wave. The complete problem of a ship's behaviour, depending as it does on wind, waves, rolling, pitching, dipping, yawing, variable head-resistance and lateral resistance,

* See Phil. Mag. Nov. 1864.
1869.

† See pp. 72, 77 of that work.

and direction of motion relatively both to wind and waves, is far too complicated even for statement in an exact mathematical form.

If a ship floating passively in the water, and without any progressive motion, were wholly without stability, her centre of gravity, centre of buoyancy, and metacentre coinciding in one point, the motion assumed by that point would be exactly that of the centre of gravity of the mass of water displaced by the ship—that is to say, it would revolve once in each wave-period in a vertical circle of the same diameter, with the orbits of the particles of water situated in the same layer.

This motion of the ship has received the name of *passive heaving*, that term being understood to comprehend the swaying from side to side, as well as the rising and sinking, of which the orbital motion is compounded.

Half the difference between the extent of heaving of the ship and the height of the waves is the extent to which, during the passage of the waves, her depth of immersion amidships is liable to be alternately increased above and diminished below her depth of immersion in smooth water. It appears that deep immersion and large horizontal dimensions, but especially deep immersion, tend to diminish the extent of the heaving motion of the ship as compared with that of the waves, and that the effect of those causes in producing this diminution is greatest among comparatively short waves.

The weight of the ship, being combined with the centrifugal force due to her heaving motion, gives a resultant reaction through her centre of gravity inclined to the vertical in a direction which, for passive heaving, is perpendicular to the wave-surface traversing the ship's centre of buoyancy (a surface which may be called the *effective wave-surface*); and that direction is the *apparent* direction of gravity on board the ship, as indicated by plumb-lines, pendulums, suspended barometers and lamps, spirit-levels, and the positions assumed by persons walking or standing on deck. The equal and opposite resulting pressure of the water, acting through the centre of buoyancy, is in like manner compounded of actions due to weight and centrifugal force; and it acts in a line normal to the effective wave-surface, that is to say, parallel to the resultant reaction of the ship. Those two forces balance each other, not when the ship's upright axis is vertical, but when it is normal to the effective wave-surface; and when she deviates from that position, they form a righting couple tending to restore her to it. Thus the stability of a ship among waves, instead of tending to keep her steady, as in smooth water, tends to keep her *upright to the effective wave-surface*; and such is the motion of any vessel or other floating body having great stability and small inertia, such as a light raft. This may be called *passive rolling*, or *rolling with the waves*.

Passive rolling is modified by the inertia of the ship, which makes her tend to perform oscillations in the same periodic time as in still water, by the impulse and resistance of the particles of water against her keel and the sharp parts of her hull, which tend, under certain circumstances, to make her roll against the waves, that is, inclining towards the nearest wave-crest, and by other circumstances.

The tendency to keep upright to the effective wave-surface may be distinguished from the tendency to keep truly upright, by calling the former *stiffness* and the latter *steadiness*. In smooth water stiffness and steadiness are the same thing; amongst waves they are different, and to a certain extent opposed; that is to say, the means used for obtaining one of those qualities are sometimes prejudicial to the other. Stiffness is favourable to the dryness of the ship, and to the power of carrying sail; steadiness is favourable

to her strength and durability, and the safety of her lading, and, in ships of war, to the power of working guns in rough weather.

A ship whose course is either oblique or transverse to the wave-crests is made by the waves to perform a series of longitudinal oscillations, which may be called *passive pitching and scending*.

In all the oscillatory movements which a ship performs among waves, two series of oscillations are combined—those in which the ship keeps time with the waves, being her passive or forced oscillations, and those which she performs in periods depending on her own mass and figure, as in smooth water, being what may be called her free oscillations. The tendency and ultimate effect of the resistance of the water is to destroy the free oscillations after a certain time, so that the forced oscillations alone are permanent.

Passive heaving, or the motion of a ship when each of her particles performs an orbital motion, similar and equal to that of a certain particle of the water in which she floats, takes place when the ship floats amongst waves without having progressive motion.

The progression of the ship, when under way, alters the action of the waves upon her in various ways, which depend mainly upon the *apparent period* of the waves relatively to the ship (that is, the interval of time between the arrival of two successive crests at the ship), and upon the *apparent slope* of the effective wave-surface in a direction athwart the ship, the latter circumstance being connected mainly with forced rolling oscillations.

When the apparent periodic time of the waves is modified by the progressive motion of the ship, the time during which the forces act which produce the heaving motion of the ship is altered in the ratio of the apparent period to the true period; and the extent of the heaving motion is also altered in a proportion which, for moderate deviations of the apparent from the true period, varies nearly as the square of that ratio. This law, however, does not continue to hold for a very great increase of the apparent period, the extent of heaving being less than the ratio first mentioned.

Hence the heaving motion of a ship is more extensive than that of the effective wave-surface, when the angle made by her course with the direction of advance of the waves is acute, and less extensive when that angle is obtuse.

Yawing, or swerving of the vessel from side to side by oscillation about an upright axis, is, when produced by the waves, the effect of the lateral swaying, which forms the horizontal component of the heaving motion, taking place with different velocities, or in opposite directions at the bow and stern of the vessel. The forces producing it are greatest when her course lies diagonally with respect to the direction of advance of the waves.

For reasons already stated, a very light and stiff ship tends to float like a raft rolling *with the waves*, and assuming at every instant the same slope with the effective wave-surface.

Let a board, having very little inertia, and no stability, be placed so as to float upright in smooth water; then, when the water is agitated by waves, that board will accompany the motions of the originally upright columns of water—that is to say, it will roll *against the waves*, inclining at every instant in a direction contrary to the slope of the effective wave-surface.

It has been shown by Mr. Scott Russell* that the condition of the broad and rounded parts of a ship, and of her hull between wind and water, is

* Trans. I. N. A. for 1863.

analogous to that of a raft; while the condition of the keel, the sharp part of the floor, and the gripe and dead wood (or fine parts of the ends) is analogous to that of the board floating edgewise, so that the ship is under the action of two conflicting sets of forces—gravity, centrifugal force, and pressure (constituting what may be called stiffness), tending to make her roll with the waves, like the raft; and the action of the water on the keel and sharp parts of the hull, which may be called *keel-resistance*, tending to make her roll against the waves, like the board, and hence that she will take some kind of intermediate motion.

It has been pointed out, however, by Mr. Froude and Professor Rankine* that there is an essential distinction between the two sets of forces before mentioned, in consequence of which, though conflicting, they are not directly opposed—namely, that the stiffness is an active force, which tends not only to prevent the ship from deviating from a position upright to the effective wave-surface, but to restore her to that position after she has left it, with a force increasing with the deviation; while the keel-resistance is merely a passive force, opposing the deviation of the ship from the position of the originally vertical columns of water, with a force depending, not on that deviation, but on the velocity of the relative motion of the ship and the particles of water, and not tending to restore the ship to any definite position. Hence those two kinds of force cannot directly counteract, but only modify one another.

For the mathematical investigation of the action of those forces reference must be made to the original papers in the 'Transactions of the Institution of Naval Architects.' The following are the general conclusions:—

The permanent rolling of a ship of very great stability, and without any sensible keel-resistance, is governed by the motion of the effective wave-surface, so that she rolls *with the waves* or like a raft.

When the period of unresisted rolling of the vessel is to the wave-period as $\sqrt{2} : 1$, the permanent rolling is wholly governed by the motion of the originally vertical columns of water: so that she rolls *against the waves*, like a board of no stability floating edgewise.

In both of the preceding cases the vessel is upright when the trough or crest of a wave passes her, and her angle of heel is equal to the steepest slope of the effective wave-surface.

When the period of unresisted rolling of the vessel is less than the above value, her upright positions occur *before* the arrival of the troughs and crests of the waves, and her angle of heel is *greater* than the steepest slope of the effective wave-surface.

The greatest angle of heel in permanent rolling occurs when the period of unresisted rolling of the ship is *equal to that of the waves*, and it exceeds the slope of the waves in a proportion which is the greater the less the keel-resistance, and becomes infinite when the keel-resistance vanishes. Thus isochronism with the waves is the worst quality that a ship can have as regards steadiness and safety.

When the period of unresisted rolling of the vessel exceeds that of the waves in a greater ratio than that of $\sqrt{2} : 1$, her upright positions occur *after* the arrival of the troughs and crests of the waves, and her angle of heel is less than the steepest slope of the waves.

The forced or passive oscillations of ships are those which produce the most severe strains, because of their continual recurrence, the free oscillations being gradually extinguished by the resistance of the water. It

* Trans. I. N. A. for 1863-64.

appears, however, that the periodic time of the free oscillations has an important influence on the extent of the forced oscillations, especially in rolling, the most unfavourable proportions for the periodic time of free rolling to that of passive rolling being those which lie near equality, and between equality and $\sqrt{2} : 1$; for the equality of these periods tends to produce an excess of rolling to which it would be difficult to fix a limit, and the ratio of $\sqrt{2} : 1$, and those near it, make the ship roll against the waves, thus throwing her into positions in which there is a risk of the wave-crests breaking into her.

A period of free rolling much less than that of passive rolling gives great stiffness, and makes the ship accompany the motions of the effective wave-surface. A period of free rolling exceeding $\sqrt{2}$ times that of passive rolling is favourable to steadiness, provided that this lengthened period be produced by the inertia of the ship, and not by insufficient statical stability.

The action of the water on a deep keel, on a sharp floor, or on fine ends below water tends to moderate the extent of rolling produced by coincidence, whether exact or approximate, of the periods of free and passive rolling; but at the same time it lessens the effect of a long period of free rolling in producing the same result.

A deep draught of water is favourable, on the whole, to steadiness, but not to stiffness.

Should the centre of gravity rise and fall relatively to the water in rolling, and the periodic time of the dipping motion so generated happen to be either exactly or nearly one half of that of the passive rolling, the result will be uneasy motion.

The steady pressure of the wind on the sails promotes steadiness, at a certain angle of heel depending on the moment of that pressure; the sudden gusts of the wind produce lurching.

As to *pitching, scending, and yawing*, it is chiefly important that, for the sake of dryness and safety, those oscillations should be performed in a lively manner among waves; and that object is best promoted by keeping the longitudinal radius of gyration short, as compared with the length of the ship—that is, by taking care not to place heavy weights in her ends.

The true principles of a ship's rolling among waves and their leading consequences were first set forth by Mr. Froude, in a series of papers in the 'Transactions of the Institution of Naval Architects,' in 1861, 1862, and 1863. Mr. Froude appears to have been the first to state the proposition that the tendency of the ship to roll among waves is primarily due to her tendency to keep upright to the effective wave-surface, and that the force which induces this tendency is very approximately the same as her *stiffness* or resistance to heeling in still water. The disposition of a ship to follow the average motion of the portion of the wave which she displaces is, however, controlled (as has been pointed out by Mr. Crossland) by the circumstances that the wave-water is continually undergoing a deformation of which the ship's hull is not susceptible. Mr. Froude has also shown* that if two plates be hinged together, so that, when in still water, they would float at an inclination of 45° to the vertical, and if the hinge be parallel to the wave-crest, the effect of the wave-motion is simply to open or close the angle between them, and not to alter (sensibly) the horizontal and vertical lines which bisect the angle externally and internally.

As there is nothing to show that the rigidity of the angle between the

* See Trans. I. N. A. vol. vi. for 1865, p. 181.

plates would tend to make any marked alteration in the invariability of direction of the bisectors, the theoretical establishment of this fact is of great importance. Its meaning is that the effect of bilge-keels is to increase the time, and, in a greater degree still, to diminish the amplitude of the oscillation, and that the use of bilge-keels is the direct mode of effecting this object.

The problem of safe rolling is not quite the same with that of easy rolling. A roll towards the wave-crest is well known as one of the most dangerous things that can happen to a ship in a high-crested sea-way, for the whole crest of the wave may then break inboard. Even when the ship follows the oscillations of the vertical lines, the wave-particles come flat on the ship's bulwarks and side. If she floats quite vertically she is still in the position of a cliff resisting a wave of the same period, whose height is the difference of heights of the surface-wave and of the mean effective wave acting upon her.

As regards the impact of a wave, the most violent blow that a wave can give is against a surface parallel to the inflexional tangent and to the wave-crest, and at a level with the line of inflexion. The motion of the particles is then normal to the wave-surface. This remark, of course, does not apply to shore-waves.

Throughout the discussion of the ship's oscillation among waves, it has been tacitly assumed that the wave-period itself might be regarded as constant. This is very far from either representing the facts or the practical problem of the shipbuilder. The wave which a vessel has to encounter may be anything, from the 11-seconds wave, 600 feet long, to a mere ripple. Practically, a vessel will not roll to waves whose length is much less than her breadth, nor will she pitch much among short waves. But, dismissing these from consideration, it may still be impossible to avoid some contingency in which a ship's period of free rolling may be equal to the wave-period. Obviously, the remedy in this case is for her commander not to keep her *broadside-on*. As a rule, no commander ever would do so in a dangerous sea-way; and even where comfort only is concerned, it is usually open to him either to shorten the effective (that is to say, the *apparent* wave-period) by putting her head a little to the swell, or to lengthen the apparent wave-period by putting her head a little off. He *must* do one of these things if he meets with actual and exact synchronism in anything like heavy weather.

As a practical matter, Professor Rankine remarks: "It would appear that a very close approximation to the form and proportions which are most favourable to steadiness has, in some cases, been realized by practical trials alone, and that independently of the steadying action of sails; for there are vessels which, when under steam alone, in any moderate swell keep their decks very nearly parallel to the horizon. It is of great importance that the lines and dimensions, and distribution of the weights of ships, which have been found by experience to possess this excellent quality, should be carefully recorded for the information of naval architects.

"On the other hand, there are vessels (especially screw-steamers) whose ordinary extent of rolling each way is from three to four times the slope of the waves."

On the subject of Waves, we refer to the following papers and treatises:—

Weber, 'Wellenlehre.'

Airy, "On Tides and Waves," *Encycl. Metropolitana* (reprinted in a separate form).

Scott Russell, Report to British Association for 1844. Also, 'Modern Naval Architecture.'

Stokes, 'Cambridge Transactions,' 1842 and 1850.

Earnshaw, 'Cambridge Transactions,' 1845.

Froude, 'Transactions of the Institution of Naval Architects,' 1862, p. 48, and (incidentally) in his papers "On Rolling." Also, "Remarks on the Differential Wave in a Stratified Fluid," Trans. I. N. A. vol. iv. for 1863, p. 216.

Rankine, 'Philosophical Transactions,' for 1863; 'Phil. Mag.,' Nov. 1864; 'Proceedings of the Royal Society,' 1868; also, 'Shipbuilding: Theoretical and Practical.'

Cialdi, 'Sul Moto ondoso del Mare.'

Caligny, papers in Liouville's Journal, 1866.

T. Stevenson, 'On Harbours.'

With regard to the rolling of ships in wave-water, we believe that almost the only exact investigations are to be found in the 'Transactions of the Institution of Naval Architects,' some of which have been reproduced in 'Shipbuilding: Theoretical and Practical,' and reprinted in the 'Engineer' and in 'Engineering.' They are as follows:—

Froude, "On the Rolling of Ships," vol. ii. for 1861, p. 180, with Appendices, vol. iii. pp. 45 & 48.

Woolley, "On the Rolling of Ships," vol. iii. for 1864, p. 1.

Crossland, "On Mr. Froude's Theory of Rolling," vol. iii. p. 7.

Rankine, on the same, vol. iii. p. 22; "On the Comparative Straining Action of different kinds of Vertical Oscillations upon a Ship," vol. iv. for 1863, p. 205.

Scott Russell, "On the Rolling of Ships," vol. iv. p. 219.

Froude, "Remarks on Mr. Scott Russell's Paper," vol. iv. p. 232.

Scott Russell, rejoinder, vol. iv. p. 276.

Woolley, Mem. on same subject, vol. iv. p. 284.

Rankine, "On the Action of Waves upon a Ship's Keel," vol. v. for 1864, p. 20. "On the Uneasy Rolling of Ships," vol. v. p. 38.

Lampart, "On the Problem of a Ship's Form," vol. vi. for 1865, p. 101.

Froude, "On the Practical Limits of the Rolling of a Ship in a Sea-way," vol. vi. p. 175.

Reed, "On the Stability of Monitors under Canvas," vol. ix. for 1868, p. 198.

An abstract of the leading principles will be found, as already stated, in 'Shipbuilding: Theoretical and Practical,' edited by Mr. Rankine.

Some valuable practical observations on the rolling of ships in waves will also be found in a pamphlet, 'Du Roulis,' by Captain Mottez, of the French Imperial Navy.

Measurement of Waves at Sea.

This is a thing which has seldom been done with any degree of accuracy. Not only is the vessel moving, but the apparent direction of gravity is not the true one. The result is, that the difference of direction between the tangents to two waves from a point a little behind the spectator is generally taken for the apparent angular height. This may evidently be far in excess of the true apparent height*.

* See Mr. Rankine's "Remarks," Trans. I. N. A. vol. iii. p. 27.

Admiral Paris has invented a self-recording instrument for the purpose of measuring both the height and form of waves. A description of this will be found in the *Trans. I. N. A.* vol. viii. 1867, p. 279. It is unfortunately a differential instrument, without any means of getting a good datum line. It appears to be much better adapted for getting approximate profiles of complex waves than for obtaining accurate measurements of simple ones.

Observations on the lengths of waves present much less difficulty: a float, sunk so as not to catch the wind (such as a bottle), and observed from a considerable height, will give the periodic time with a fair degree of accuracy, and the length may be inferred from the period.

General observations upon waves* are not in point. The object in the present case is to ascertain what the particular waves are in which the ship's rolling is being observed.

Measurement of Rolling.

It is very well known that a pendulum at sea does not give a vertical line, but a direction due to the joint effect of gravity, of its own free oscillation, and of the forced oscillation due to the motion of its point of suspension. A suspended clinometer is thus perfectly useless for this purpose. Barometers, caddy-lamps, and chandeliers generally oscillate through larger angles than the ship.

Mr. Froude (*Trans. I. N. A.* for 1862, p. 41) suggests watching the rattlins of the rigging come down to the horizon, as a ready and fairly correct way of measuring the roll. The motion of the mast-heads relatively to the stars may be used in the same way.

M. Normand, jun., of Havre, has invented a very ingenious clinometer suspended on gymbals, like a chronometer, in such a way as to be as little as possible influenced by the ship's motion†. We do not consider that any instrument depending upon gravitation is to be relied upon at sea, and we have been informed that M. Normand himself is not quite satisfied with his instrument.

Apart from observations depending on the stars, or actual sea-horizon, the only instrument that can be relied upon as giving an invariable plane is of the gyroscope class. A modification of Foucault's gyroscope was tried in the North Sea in 1859, by Professor C. Piazzì Smyth, who gave an account of the instrument and its performance in the *Trans. I. N. A.* for 1863, p. 118.

An instrument upon the same rotatory principle, but self-recording, has been invented by Admiral Paris, Hydrographer of the French Imperial Navy. It consists of a spinning top, with its point of support above its centre of gravity. It spins in an agate cup, and the top of the spindle carries a camel's-hair pencil which marks a paper band, driven by clock-work, and passing through bent guides so as to keep close to the pencil. It is described, and some of its curves copied, in the *Trans. I. N. A.* vol. viii. for 1867.

What these instruments really give is the deviation from an undetermined direction. They therefore give the time of rolling or pitching, and of any intermediate oscillation of a periodic character, and the amplitude of

* Although very desirable for other reasons.

† See *Trans. I. N. A.* for 1866, p. 187.

deviation from the mean line; but they evidently would not disclose any steady inclination to which the rolling might be superadded.

The gyroscope or top will, of course, have its own proper oscillatory revolution, which, however, soon spins out, on the same principle that a peg-top "sleeps."

On the whole, there does not seem to be much room for improvement in Admiral Paris's instrument, unless, perhaps, in diminishing the atmospheric resistance. Possibly also provision might be made for adjusting the point of support to the centre of gravity.

Recommendation of Experiments on Rolling.

The mathematical theory of rolling is very far from easy, and leads to equations of which there is no known solution. The time of a common pendulum, for instance, depends upon an elliptic integral, and, beyond the degree of complexity involved in such a function, mathematics are in the condition of uncleared ground. Accordingly, while it is possible to give a rational account of the immediate gross results of a compound oscillation, these results cannot be expressed or measured with the requisite combination of generality and accuracy. In order to treat them, we are obliged to introduce simplifying suppositions, which do not necessarily belong to our problem—as, for instance, isochronism, or the neglect of certain elements of resistance, or the grouping of others.

Now, when this occurs with any branch of practical knowledge, the proper mode of applying mathematical investigation is to start, not from the known principles of general mechanics, but from an advanced base of observations peculiar to the science itself. In hydrodynamics, between minuteness and number, the ultimate molecular unit escapes our notice, and we are only able to observe effects in the gross; being thereby driven to a certain want of detail, both of observation and of reasoning, which allows us to trust our conclusions only when they have been made to rest on a broad experimental foundation. Whether we regard the theory of the propulsion of ships, or that of their rolling, our analysis has assuredly been pushed quite to the extreme verge to which general reasoning can be trusted; and a largely increased extent of exact observation ought to precede further attempts at inductive reasoning on these subjects. We have many exact experiments on propulsion, although, from the complicated character of the phenomena involved, it is difficult to separate the issues; and this will probably not be set right without further special investigation. With regard to rolling, however, we have much vague observation, and but little exact knowledge derived from experiment.

We are not aware of any one published experiment on the rolling of ships in waves in which the details necessary to make any mathematical use of the results are supplied. The data required are, as a minimum for each case,—

1. A draught of the ship, and her calculated elements.
2. The position of her centre of gravity.
3. Her periodic time in still water.
4. The condition of her wet surface.
5. The extent and period of her roll.
6. Was the rolling simple, or mixed with pitching?
7. The height, length, and period of the waves in which she was rolling.
8. Were these waves simple?
9. What alterations have been made in her displacement, her trim, and

the position of her weights, as regards both centre of gravity and moment of inertia, previously to the trial?

10. Force and direction of wind, and condition of ship as regards resistance to it.

11. Full details as to manner in which, and the instruments or calculations by which, these data have been ascertained.

There is no doubt that for a comprehensive view of the subject, it would be necessary that these things should be ascertained with care for a large number of ships, of various classes, and under very varied conditions. But this is too much to expect to get done, although we think it would be a good thing for the Government, and other large shipowners, to keep in view as an ultimate object. Meanwhile we think it would be a very great experimental aid to science if these things could be accurately settled for even two or three ships, under different circumstances of weather and different arrangements of weight, both in amount and distribution.

Similar experiments should also be made with reference to pitching.

The trials should be made with sails furled, and as little disturbance from headway as possible. We have every wish to have parallel experiments tried under any possible conditions of sail and propulsion, and, if it may be done, on the same ships, consecutively with the simpler experiments; but it will be seen that the data are already sufficiently complex at the best, and that they must be used clear of headway and leeway before they can be discussed with reference to these.

No experiments are of use for the purpose of inductive reasoning in which any one of the data mentioned above are wanting.

We think that the Government might fairly be asked to institute such a set of calculations and experiments. We cannot find that the exact information which we have suggested is in existence anywhere. We are certain that it has not been published in any available form; and we have reason to believe that the knowledge is quite as much needed and desired by the gentlemen responsible for the construction of the navy as by merchant builders or by students of theory.

We therefore recommend that the deputation previously mentioned with reference to the experiments on resistance be also instructed to urge upon the Admiralty the importance, both practical and theoretical, of instituting such a set of experiments, of providing suitable instruments for recording exact observations, and of publishing the results. We also recommend the appointment by the Council of the Association of a committee of *three* members to confer with the officers of the Admiralty as to the drawing up of detailed instructions for conducting these experiments; and that the Lords of the Admiralty, in the event of their assenting to the proposals, be requested to nominate a committee to confer with the committee named by the Association.

In conclusion, we beg leave to recommend that this Report be officially communicated to the Councils of the Institution of Naval Architects, the Institution of Civil Engineers, and the Institution of Engineers in Scotland, and the cooperation of those bodies sought, both in applying to the Government and in making known among shipbuilders, and other persons connected with Naval Architecture, as well what is the state of our existing knowledge as what are the immediate desiderata for its extension.

CHARLES W. MERRIFIELD.
GEORGE P. BIDDER.
DOUGLAS GALTON.

W. J. MACQUORN RANKINE.
W. FROUDE (*subject to the following explanations*).

Mr. Froude's Explanations.

The subject of a ship's resistance is one which I have for many years been independently investigating, both theoretically and experimentally; and I have been thus led to conclusions which are in very material respects at variance with those which Mr. Merrifield has placed on record for the Committee as representing the existing state of knowledge respecting it, and specially at variance with the consequent recommendations which he has drawn up, as indicating the experiments for the performance of which the assistance of Her Majesty's Government is to be sought: I thus find myself somewhat abruptly placed in a position in which I must ask permission to present, as part of our proceedings, a supplementary report explaining the reasons which oblige me to dissent from the recommendations to which I refer. Until the Draft Report was in my hands, I was unaware that "Resistance" was regarded as included in the list of subjects submitted to the Committee; for I understood the terms "Stability" and "Sea-going qualities" as having reference to the theory of "Rolling motion," and "Propulsion" to the theory of the Action of Propellers. The subject of Resistance appeared to belong already to the "Steamship Performance Committee."

Let me say at the outset that Mr. Merrifield's very full discussion of this subject appears to me to set forth most lucidly what must be called "the existing state of knowledge" respecting it; it has evidently involved much laborious research and deep consideration.

And, on the other hand, the results at which I have arrived are in many respects so far from complete that I have hitherto hesitated to bring them before the public. But I believe I have so fully established those conclusions, to which I shall now refer, and the difference in the line of action to which they point is so serious that, under the present circumstances, I feel bound to press them on the notice of the Committee.

The Report specially recommends, as the experiment which it is important to try, the dynamometric determination of the scale of resistances for a full-sized ship.

Now, without impugning, or rather, while fully asserting that any scale of resistance, in terms of velocity, accurately determined for a full-sized ship, would be of real value and of great interest, I shall nevertheless contend (1) that experiments on the resistances of models of rational size, when rationally dealt with, by no means deserve the mistrust with which they are usually regarded, but, on the contrary, can be relied on as truly representing the resistances of the ships of which they are the models; and (2) that in order properly to open up the question, so great a variety of forms ought to be tried that it would be impossible, alike on the score of time and expenditure, to perform the experiments with full-sized ships. Both these propositions require to be drawn out at some length. The kindred proposition, that as accurate results can be obtained far more easily and rapidly in experimenting with a model than with a ship, though of great importance, is so obviously true as to require no elucidation.

The natural expectation that the ascertained resistance of a model will furnish a measure of the resistance of a ship similar to the model, depends on the *primâ facie* probability that the resistance for a given body will vary as the square of its velocity; and that in comparing similar bodies of different dimension at a given velocity, the resistance will be as the square of the dimension, since that function expresses alike the proportion of the respective midship sections and of the respective friction-bearing surfaces. Were

these propositions true, the ascertained resistance of a model, at given velocity, would supply a complete scale of resistance for all velocities, both for the model and for any ship similar to the model.

Since, however, the resistance of a model or ship deviates from the law of the square of the velocity, as under certain circumstances it is known to do, in a manner dependent on its actual dimensions, it is obvious that the simple scale of comparison, which seemed *prima facie* probable, can be no longer accepted, and it has hence been hastily concluded that no assignable scale of comparison can be found instead.

Now it appears to me to be pretty well established, and it is scarcely questioned, that, for deeply submerged bodies of tolerable size and fair shape, the resistance does follow the law of the squares with a high degree of approximation. Such deviations from this law as appear in Beaufoy's experiments are, I think, explicable by the angularity of the shapes tried and by the mode of trying the experiments, under which the considerable distance between the bodies tried and the conducting float by which they were carried involved some deviation of the body from true axial motion, when the velocity and the consequent resistance became considerable.

That surface-friction, in particular, follows the law of the squares of the velocity very closely, is well established by the experience of the flow of water through pipes, in reference to which, I may observe, I have myself experimentally verified on a five-mile length of 9-inch pipe, the law that the delivery is almost exactly as the square root of the steepness of the hydraulic gradient. The experiments were tried with very great variations in the steepness*. Now Professor Rankine's admirable stream-line investigations have definitely established the conclusion that for symmetrically shaped bodies of "fair" lines, not excluding by that description certain very blunt-ended ovals, when wholly submerged, the entire resistance depends on the conditions of imperfect fluidity, of which surface-friction is the only one so considerable that we need take account of if we deal with bodies of rational dimensions; and this, as I have pointed out, does follow the law of the squares. I set aside the condition of "viscosity"; for though this defect, even as it exists in water, is certainly sufficient to affect differently the resistances of bodies of different dimensions, this is not sensibly the case unless the bodies are very minute; and having regard to the great vitality of such small surface-waves as (say) one foot in length, and to the fact that discharge of water through pipes and orifices exhibits no results indicative of this special action, unless the diameters are very small indeed, it seems extremely improbable that the resistances of bodies five or six feet in length will be affected by it. If, therefore, we were dealing with submerged bodies, we should have no reason to mistrust the *prima facie* deductions founded on experiments with models.

When, however, we deal with a body moving at the surface, we at once meet with a *vera causa*, which alters those simple relations that exist between the resistances of differently dimensioned submerged bodies. This *vera causa* is the generation of surface-waves, which accompanies the transit of the body along the surface; and it is, I believe, not merely the only known cause, but a sufficient one.

What absolute conformation and magnitude of waves a given vessel moving with a given velocity may create, and what excess of resistance may thus be

* Though I regard these experiments as sufficiently conclusive in reference to the point to which they were directed, I am inclined to think that the theory of surface-friction in its application to a ship's resistance requires considerable revision.

developed in any individual instance, it is not necessary for the present purpose to determine; for it will appear that, whatever the excess may be, however abnormally, in virtue of it, the law of resistance for any given ship may vary in terms of her velocity, a very simple scale of comparison will express the relation between the excess as developed in a model and as developed in a ship similar to the model when moving at a corresponding velocity. I shall show, in fact, that if the velocities of the ship and the model are as the square roots, these excesses of resistance thus arising will be as the cubes of their respective dimensions, a law which, as is easily seen, expresses also the relation founded on those elements of resistance which vary as the square of the velocity and as the squares of the respective dimensions.

The principles on which Professor Rankine's stream-line investigations are founded establish generally, in relation to all wholly submerged symmetrical bodies moving in a fluid infinitely extended on all sides, that the stream-line displacements which the motion of the body imposes on the surrounding volumes of fluid are, for a given body, identical in configuration for all velocities (an identity which assigns to them always a velocity proportional to that of the body itself), and that the configuration is similar for all similar bodies.

If we now suppose that the body is moving along the surface of the fluid, and if we imagine the surface to be not under the influence of gravity or any such force, it is obvious that here also the configurations of the stream-line displacements will be identical at all velocities for the same body, and will be similar for similar bodies, including those displacements which consist of upward disturbances of the surface.

When we impose the further condition appropriate to an existing water-surface, that the replacements of the surface, when disturbed, are governed jointly by gravity and by the volumes and velocities of the original impulses of disturbance, it follows that those impulses of disturbance, being similar for all similar bodies at all velocities, will retain their similarity wherever and in the manner which the operation of gravity permits: and this will be when the similar bodies are moved with velocities proportioned to the square roots of their respective dimensions; in these a similar wave-configuration will, in each case, similarly dispose of the originally similar volume of displacement, since similar waves have their velocities so related.

These waves (as is explained by Professor Rankine), when the velocity proper to their length along the line of motion is exceeded by that of the ship, so that they cannot squarely travel with her, satisfy the conditions of their motion by travelling obliquely, and diverging into the surrounding fluid, the angle of divergence and their size forming a measure of the work constantly running away from the ship, and consequently of the resistance caused by their generation.

Now the similarity of the configuration which has been asserted involves the condition that when the velocities of similar ships are as the square roots of their respective dimensions, the angles of divergence will be equal, and therefore equal lengths of similar wave-crest will be "run off" for equal distances travelled by the respective ships; and hence the energy abstracted in each case by these equal lengths of similar wave-crest is clearly as the cube of the dimension (since the mass elevated is as the sectional area, and the elevation is simply as the dimension); and since the forces which supply proportionate amounts of energy while travelling a given distance must be as the energy, it follows that the excesses of resistance thus called into existence are also as the cube of the dimension, agreeing in this respect, as

has already been pointed out, with the resistances derived from the surface-friction. In fact, we are thus brought to the scale of comparison which was just now enunciated, that the entire resistances of a ship, and similar model, are as the cubes of their respective dimensions, if their velocities are as the square roots of their dimensions.

In verification and illustration of the foregoing views, I tried, in the autumn of 1867, a large number of resistance-experiments with a pair of models of contrasted forms, six feet long, by towing them simultaneously from the ends of a pair of ten-foot scale-beams connected with self-recording dynamometric apparatus, and mounted on booms projecting sideways from the nose of a steam-launch, lent me for the purpose by Mr. Bidder. The water-lines of the models are shown in Plate I. fig. 1. One was of the wave-line type, the other, having the same length, form of midship-section, and displacement, had large rounded ends. I also tried similar experiments with a pair of very nearly similar models of twice the dimensions and eight times the displacement. I had already obtained a series of experimental results of the same kind, but with less successful apparatus, from a similar pair of models, three feet long. These data enabled me to compile for each model a diagram of resistance in terms of velocity.

The three pairs of such diagrams, proper to the three pairs of models, were laid down to scales corresponding to the dimensions of the models, according to the system of comparison I have enunciated; thus the velocity-scale for the six-foot models is $\sqrt{2}$ times, and that for the three-foot models twice as open as that for the twelve-foot models; and the resistance-scales for the six-foot and three-foot are respectively 8 and 64 times as open as that for the twelve-foot. According to my proposition, were the three sets of models exactly similar the three sets of diagrams should be identical.

Reduced copies of these diagrams are shown in Plate I. figs. 2, 3, 4. Their general agreement, especially as to the position occupied in the velocity-scale by the several salient features of the curves and as to the relative resistances of the contrasted forms, is very striking. It is true that on comparing the absolute resistances, the correspondence is not so close as it at first sight appears. Thus the three-foot models exhibit throughout a decided excess of resistance as compared with the six-foot; but I think this is probably attributable to their being small enough to be within the range of viscosity. On comparing the diagrams of the twelve-foot and six-foot models, however, we find that it is the larger model that has an excess of resistance. This excess, which is slight, may be partly due to certain minor differences of form which had been introduced in the larger models. It may also have partly arisen from the fact that the twelve-foot models, owing to their greater dimensions, swam relatively nearer to the towing-boat, a circumstance which may naturally have tended to enhance their resistances.

On the whole, I think that series of diagrams supplies a very fair verification of the alleged scale of comparison.

Besides thus throwing light on the question of comparison of the performance of similar vessels of different dimensions, these experiments show very clearly that strange forms may possess merits that are entirely unknown and unexpected before experiment is made upon them; for here we find that an abnormal form (suggested simply by the appearance of water-birds when swimming), if moving with a high though not excessive velocity, experiences considerably less resistance than the wave-line form, the accredited representative of the form of least resistance, particularly at high

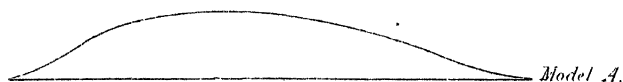


Fig. 1

Half Water lines of the Models

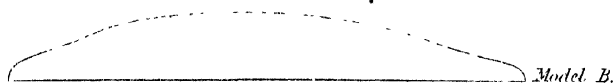


Fig. 2

Diagrams of 12 ft. Models

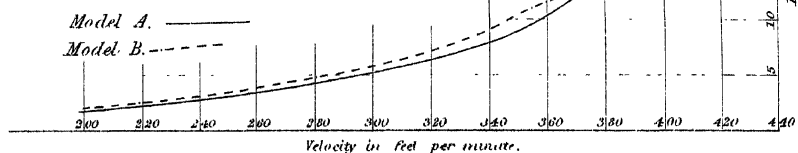


Fig. 3.

Diagrams of 6 ft. Models.

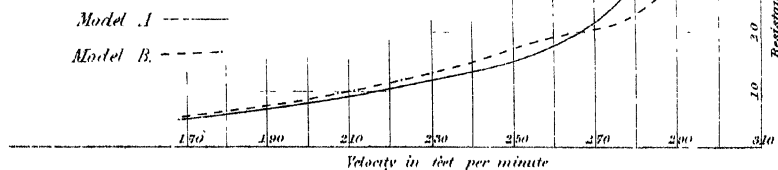
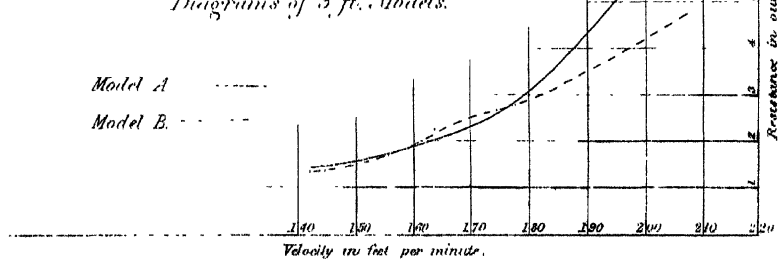


Fig. 4

Diagrams of 3 ft. Models.



speeds. This proves that we can have no ground for certainty that we have found even an approximation to the best form, unless we have gone experimentally over almost the whole ground and tested a very wide variety of shape. But, independently of this aspect of the question, it is, I think, certain that on very many important questions, such as, for instance, the proper ratio of length to breadth, there is no really established principle of judgment on which reliance can be placed. Yet most weighty considerations affecting economy and efficiency are involved in the settlement of even that single question. But unless we build mere experimental ship-sized models, there seems no possibility of determining the question by full-scale experiments.

It is true that the circumstances under which my experiments were tried did not admit of such exactness as to render them absolutely conclusive as the sole basis of the theory of comparative resistance in terms of dimension. Nor do I by any means pretend to be certain that there are no elements of resistance other than I have taken account of in my theoretical justification of it; but if any such do exist, they can be detected, and the laws of their operation discovered with far greater facility and completeness by small-scale than by full-size experiments. And I contend that unless the reliability of small-scale experiments is emphatically disproved, it is useless to spend vast sums of money upon full-size trials, which, after all, may be misdirected, unless the ground is thoroughly cleared beforehand by an exhaustive investigation on small scale.

Report of the Committee appointed to consider and report how far Coroners' Inquisitions are satisfactory Tribunals for the Investigation of Boiler Explosions, and how these Tribunals may be improved, the Committee consisting of WILLIAM FAIRBAIRN, C.E., F.R.S., LL.D., &c., JOSEPH WHITWORTH, C.E., F.R.S., JOHN PENN, C.E., F.R.S., JOHN HICK, C.E., M.P., FREDERICK J. BRAMWELL, C.E., THOMAS WEBSTER, Q.C., HUGH MASON, SAMUEL RIGBY, WILLIAM RICHARDSON, C.E., and E. LAVINGTON FLETCHER, C.E.

I. BOILER explosions continue to occur with their accustomed frequency and fatality. Since the Meeting of the British Association held last year in Norwich not less than 46 explosions have occurred, by which 78 persons have been killed, in addition to 114 others having been injured; and as these catastrophes take place with considerable regularity, there is every reason to apprehend that a similar number of explosions, causing the loss of a similar number of lives and a similar amount of bodily injury, will transpire before the next Meeting of the British Association, unless some very immediate measures are adopted for arresting these sad disasters.

The fearful explosion which occurred on the 9th of June last, at Bingley, by which as many as fifteen persons were killed and thirty-three others injured, some of them very seriously, will be fresh in the remembrance of every one; more especially from the fact that amongst those killed and injured were a number of women, having no connexion whatever with the works at which the explosion occurred, as well as a number of little children. These children were exercising in an adjoining playground, when just as

they were passing close to the wall of a two-storied building on the premises at which the explosion occurred, the boiler burst, demolishing the building, burying the children in the ruins, and crushing eight of them to death, in addition to seriously injuring seventeen others.

Sad as it is when those connected with boilers and who gain their livelihood from working them are injured, it is even more so when outsiders, who have no interest in their use or control over their management, are victimized by their explosion, more especially when these victims are women and children. Such, however, is by no means an infrequent occurrence. In one case, a child asleep in its bed, unconscious of all danger, was killed on the spot by a fragment of an exploded boiler sent through the roof like a thunder-bolt. In a second case, a young woman working at her needle in an upstairs room in her own dwelling, was struck by a boiler which was hurled from its seat, and dashed against the window at which she sat. The injury she received was serious; her leg had to be amputated, and death shortly after ensued. In a third case, just as an infant was making its first assay at walking across the kitchen-floor in a collier's cottage, a fragment of an exploded boiler came crashing through the roof, and striking down the child, killed it on the spot. In a fourth case, a woman was standing at her own cottage-door with an infant in her arms, when one of the bricks sent flying by the bursting of a boiler struck her little one on the head, and killed it in its mother's arms. In a fifth case, a group of boys were sporting in a meadow, when the boiler of a locomotive engine, just drawn up at an adjoining railway-station, burst, and scattering one of its fragments among the group, killed one of the boys on the spot, and injured another. In a sixth case, a house in which an infirm old woman lived, confined to her bed in an upstairs room, was demolished by a boiler explosion, so that the poor woman, with the bed on which she lay, was rudely brought to the ground. In a seventh case, a man passing through a public thoroughfare on horseback was struck by the débris showered around by a boiler that happened to explode at the moment; so that even those casually passing by the premises at which steam-power is employed are not safe from the attacks of bad boilers. It is no uncommon thing for dwelling-houses in the vicinity of boilers to be invaded on the occurrence of an explosion with huge fragments, and to have their windows and roofs riddled as if they had been bombarded, while in some cases they are altogether demolished. Many other cases similar to the above might be added; but the facts already given are, it is thought, sufficient to show that those who use steam-boilers are not the only parties who suffer from their explosion. Thus the subject acquires a wider interest, and becomes not only important to steam-users, but also to the public at large.

It is therefore desirable that public attention should be thoroughly aroused on the subject of steam-boiler explosions, while it is clearly well worthy of the consideration of the Members of the British Association.

II. The Committee pass on, in the second place, to state that the attention of its Members has for years been directed to the cause of these sad catastrophes, and that they have invariably found that steam-boiler explosions, though so complicated and disastrous in their results, have sprung from causes of the simplest character.

In some cases explosions arise from the boilers having been originally mal-constructed, the furnace-tubes, for instance, not having been strengthened, as experience has shown to be necessary, by encircling rings or flanged seams, or other approved and suitable means; and, in consequence of the neglect of these simple precautions, which may readily be adopted by any one, a con-

siderable number of furnace-tubes have collapsed and ruptured, when the rush of steam and hot water resulting therefrom has been attended with the most disastrous consequences both to life and property. Explosions of this character are particularly prevalent in Cornwall, where it seems especially difficult to persuade steam-users that a furnace-tube can collapse from any other cause than that of overheating through shortness of water. This simple but obstinate prejudice makes Cornwall one of the most prolific counties for steam-boiler explosions; and the Cornish boiler, which, when well constructed and strengthened in the furnace-tube as just described, is one of the safest and most reliable of any, has been raised to the undesirable notoriety of being the most explosive, simply through the obstinate prejudice just referred to, so that the very county that gave this boiler birth and name is doing more than any other to damage its reputation.

Other explosions arise simply through defective staying, as in the case of the boiler that exploded at Aberaman on the 31st of May last, killing four persons and injuring four others. In this case the front end of the boiler was blown out, consequent on the removal of the furnace-tube in order to metamorphose the boiler (most unwisely) from one fired internally to one fired externally. When the furnace-tube, which formed a most valuable longitudinal stay, had been removed, no adequate provision was made for repairing its loss, and the consequence was that the end blew out from sheer weakness. This explosion is by no means singular; and many similar cases have been met with in which the flat ends of boilers have been blown out through unwisely removing the furnace-tube in Cornish boilers in order to exchange internal firing for external. One other explosion, resulting from imperfect staying, may be referred to, which occurred on the 28th of July, 1866, at Tunstall, and resulted in the death of two persons and in injury to seven others. This boiler was of considerable size, being as much as 36 feet long by 9 feet diameter, while it was worked at a pressure of from 35 lbs. to 40 lbs. on the square inch. This boiler, which contained an internal horseshoe-shaped flue, was constructed with a hemispherical end at the back, and a flat one at the front. The flat end was insufficiently stayed, in consequence of which it was blown out with the horseshoe-shaped tube attached to it, and thrown to a distance of about 50 yards in one direction, while the shell of the boiler recoiled to about the same distance in another. Alongside this boiler was another, in process of completion, with two boiler-makers and a boy at work inside it. On the occurrence of the explosion, not only was the boiler first referred to torn from its seat, as just explained, but the sister one alongside was thrown on to a public road, and as this road happened to be on an incline, the boiler went rolling down, with the men, the boy, and their tools inside it, so that their predicament was somewhat similar to that of poor Regulus in his spiked cask.

Other explosions occur from defective material and workmanship, in illustration of which, the explosion may be referred to which occurred at Norwich on the 25th of September, 1866, by which the works were laid in ruins, seven persons killed, and two others injured.

Other explosions, again, arise from defective equipments, the manholes not being guarded by substantial mouth-pieces, or the boilers not being mounted with suitable safety-valves, glass water-gauges, or other necessary fittings.

Many explosions occur from the worn-out state of the boilers, the boilers being worked on till the plates are so reduced as to be no thicker than a sheet of brown paper. One such case occurred on the 24th of April, 1865, at Wigan, and resulted in the death of one person, and in injury to four

others. Another took place at Leeds on the 27th of March, 1866, by which two persons were killed, and six others injured. A third happened at Collyhurst, Manchester, on the 23rd of December, 1867, by which six persons were killed and four others injured. Cases of this class are so numerous that they defy enumeration, and the working on of old worn-out boilers, that should long since have been discarded altogether, is a prolific source of explosions.

Some explosions arise from neglect of the attendants, who have ignorantly tampered with the safety-valves, or neglected the proper supply of water. The number of explosions from this cause, however, is not by any means so great in proportion to those that arise from malconstructed or worn-out boilers, as is generally supposed; and many more explosions arise from bad boilers than from bad attendants, though it is often much to the convenience of the steam-user to have the blame of an explosion thrown upon the attendant rather than on the boiler.

Such are some of the leading causes of steam-boiler explosions, all of which, it will be seen, are extremely simple; and the Committee consider that, as a rule, boilers burst simply because they are bad—bad either from original malconstruction, or from the condition into which they have been allowed to fall; while they wish to record their opinion that those lamentable catastrophes, by which so many persons are annually killed, are not accidental, but that they might be prevented by the exercise of *common knowledge and common care*.

III. The next point the Committee have to consider is, how far the present inquiries conducted by coroners as to the cause of boiler-explosions are satisfactory.

On referring to the verdicts returned by coroners' juries on deaths occasioned by boiler-explosions, it appears that the usual verdict is one of "accidental death;" in fact this seems to be returned on nearly every occasion, whatever the cause of the explosion may be, and even when it has resulted from the use of an old worn-out boiler, reduced to the thickness of a sixpence. Added to this, the evidence commonly given at these inquiries is anything but of a reliable and instructive character. The most visionary theories are advanced, and the attempt is frequently made to show that explosions are unaccountable and inevitable. Thus no suitable information is given to the public as to the cause of these sad disasters, and the consequence is that boiler-makers can palm off on the public bad boilers, and steam-users employ them with the certainty that if they explode with fatal consequences, they will, by the help of a coroner and his jury, be publicly absolved from all responsibility, and the event proclaimed to be accidental. After the conclusion the Committee have arrived at, that explosions are not accidental, but may be prevented by the exercise of "*common knowledge and common care*," they cannot but consider that such evidence and such verdicts are eminently unsatisfactory, and that they call for immediate attention.

IV. In the fourth place, the Committee have to consider how far the present unsatisfactory character of coroners' investigations can be corrected.

It has been proposed by the Manchester Steam-users' Association that every coroner, when holding an inquiry on a steam-boiler explosion, should be both *empowered and instructed* to avail himself of the assistance of two competent engineers having no connexion with the works at which the explosion occurred, and that these engineers should visit the scene of the catastrophe, investigate the cause of the explosion, and attend the inquest in order to assist the coroner in his examination of witnesses, as well as to give

evidence themselves before the jury, and report on the cause of the explosion, their reports (which might either be joint or several, as found most convenient in each case) being accompanied with explanatory scaled drawings, showing the original construction of the boiler, and as far as possible the liues of rent, as well as the direction in which the parts were thrown, and the distances at which they fell; while, in order to secure to the public the full advantage of the investigation, it is further proposed that the engineers' reports, with the accompanying drawings, along with the verdict of the jury, should be printed and deposited in the Patent Office, and lie there for inspection and purchase, as in the case of specifications of inventions; and also that copies of these Reports should be forwarded to the members of both Houses of Parliament, as in the case of reports on railway catastrophes, as well as to the various free libraries and scientific societies throughout the country.

The Committee consider that the adoption of this proposition would very much raise the character of the present inquiries conducted by coroners, and that the measure is well calculated to secure the truth being fully arrived at and plainly spoken, to which they attach the greatest importance.

The fact of two engineers being appointed to investigate and report, those engineers being altogether independent of the works at which the explosion occurred, would, it is thought, secure an unbiassed opinion, while from the publicity given to the verdict, the coroner and jury would be stimulated to make a searching investigation. It is possible that in some cases, more especially in the early adoption of this plan, some coroners might not select the most competent engineers to assist them in their inquiry; but this, it is thought, is an error that would soon be corrected from the publicity it is proposed to give to the whole proceedings, which would make the coroners careful to make a wise selection for the sake of their own reputation, while, as they would not be limited in their choice to a special locality, but might take the range of the whole country, there would be no difficulty in their finding thoroughly competent men. Were two competent engineers selected, the Committee consider there would never, or at all events but very seldom, be any practical difference in their views as to the cause of an explosion; but presuming that in a few instances such might be the case, the Committee would not recommend that, as a rule, a third party should be called in to decide the point, since such a question should not be decided simply by a majority of opinions. The better plan would be to record the facts and the conclusions arrived at, and to leave to public discussion and time to show how far the opinions advanced were correct or not.

One of the results of searching investigations and plain-speaking verdicts would be, that when a steam-user has killed some half dozen people by the use of a crazy old boiler, the widows and children of the deceased would be able to claim from him compensation for the loss of their bread-winners. This, it is thought, would operate as a most wholesome check both upon boiler-makers and boiler-users, as the one party would be exposed if he sold a bad boiler, and the other if he bought it. Some timid steam-users object to this measure, lest they should over be brought in for heavy damages; but such fears may be altogether dismissed by all those who are working honest boilers. Good boilers, as already stated in this Report, do not burst. Explosions are not mysterious, inexplicable, or unavoidable. They do not happen by caprice, alike to the careful and the careless. They may all be prevented by the exercise of common knowledge and common care, so that timid steam-users may dismiss their apprehensions as long as they are doing their duty by

their boilers and boiler-attendants. These improved investigations would at the same time have a most wholesome effect upon the operations of boiler-inspection associations and boiler-insurance companies, as in the event of the explosion of an enrolled boiler, the case would be fully investigated by impartial parties, and the facts brought to light. Such a course would clearly promote sound inspection.

Thus the Committee consider that the adoption of this measure would have so wholesome an influence upon boiler-makers and boiler-users, as well as upon boiler-attendants and boiler-inspectors, and indeed upon all those connected with the use of steam, that it would, without any further Governmental interference, do much to prevent the recurrence of steam-boiler explosions, and they warmly concur with the proposition.

With regard to the manner in which the expense of these investigations should be defrayed, the Committee recommend that this should be met from the same source that coroners' inquiries are met at present, viz. either from the county or city rates, as the case may be. This course is deemed better than that of throwing the cost of the inquiry upon the owner of the exploded boiler by way of penalty, as in many cases his resources would be so drained by the catastrophe as to be insufficient to meet the charges; while, in addition, it is thought that scientific witnesses, called upon to discharge so important a public duty as that now proposed, should not be dependent on so uncertain and invidious a source for remuneration.

It has been proposed that the Crown should levy a heavy *deodand* on the owners of all boilers that explode, unless it could be shown that the explosion arose from causes entirely beyond their own control, the onus of the proof being thrown on the boiler-owners, and not on the Crown. Such a measure has, at first sight, much to recommend it. It would doubtless act as a powerful stimulant to care; but inasmuch as the relatives of those killed by boiler explosions are deprived thereby of their means of support, it is thought that all payment should go to them in the way of compensation rather than to the Crown. In many cases the owner of a boiler is so impoverished by its explosion that, had he to pay a *deodand*, he would have nothing left to compensate those who were rendered widows and orphans by the catastrophe, so that the Crown would be robbing them of their legitimate compensation. It is thought therefore it would be better not to impose any *deodand*, fine, or penalty, but to leave the steam-user, in the event of explosion, simply to the exposure of full investigation and plain speaking, combined with the liability to an action for damages, which the improved verdicts would give increased facilities for setting in motion.

The Committee would wish to add a few remarks upon the misapprehension that arises from the use of the word "*accidental*" in the verdicts returned by coroners' juries, and the advantage they think would be derived from the substitution of the expression "*not due to malice aforethought*." The Committee apprehend that the fundamental object of a coroner's inquiry, in the case of a sudden or violent death, is to determine whether that death was occasioned by personal malice or not. Thus it may be legally correct for the jury to return a verdict of "*accidental death*" from a steam-boiler explosion, though the boiler may have been so worn out that, in an engineering and common sense view, the explosion was no accident at all. Thus the jury use the word in one sense, but the public accept it in another, and the term is taken to be an exoneration of the owner of the boiler. It is thought that the obligations of the jury would be fulfilled, at the same time that the prevention of steam-boiler explosions would be promoted, if juries, instead of

returning a verdict of "*accidental death*," would state that they consider there had been no "*malice aforethought*," and the following verdict is given by way of illustration:—

"The jury find that X., X., &c. were killed by a steam-boiler explosion that occurred at — street, in — town, on — day of the week, month, and year, on the premises occupied by —; and while they consider that these deaths were not occasioned by any '*malice aforethought*,' either on the part of the owner of the boiler or others connected with it, they wish to record the fact that the boiler was a bad one, its plates being considerably reduced by corrosion, and that it was to this cause that the explosion was due."

The Committee do not overlook the fact that juries have a third course open to them, which lies between the announcement of "*accidental death*" or "*wilful murder*," and that they have the power of committing owners of boilers for "*manslaughter*," a power which in many cases they are bound in the discharge of their duty to exercise, and in the opinion of the Committee much more frequently than they do. The task, however, of committing a boiler-owner for manslaughter is frequently an invidious one for a coroner's jury, and in practice verdicts of manslaughter are very seldom brought in by them. Were the suggestion thus made carried out, coroners' juries would be extricated from an unpleasant position, and the truth with regard to explosions would be more fully and freely spoken.

The following is a recapitulation of the conclusions to which the Committee have arrived:—First, that a lamentable loss of life is annually caused by steam-boiler explosions, which urgently calls for public attention. Secondly, that these explosions, as a rule, are not accidental, but may be prevented by the exercise of "*common knowledge and common care*." Thirdly, that the present investigations conducted by coroners with regard to steam-boiler explosions are eminently unsatisfactory, and call for immediate improvement. Fourthly, that coroners should, when conducting inquiries on boiler explosions, be *instructed and empowered* to avail themselves of competent engineering advice, so that the cause of every boiler explosion may be fully investigated, while the information acquired should be widely circulated. Fifthly, the Committee entertain a sanguine hope that this course alone would do much towards the prevention of the present recurrence of steam-boiler explosions, without any further Governmental action.

Before concluding this Report, the Committee feel it incumbent upon them to allude to the general movement that has taken place within the last year with regard to the adoption of some system of compulsory inspection.

During the past session a Bill was introduced to Parliament, and carried through an early stage, for placing all steam-boilers under Government inspection, by the agency of the Board of Trade. By others it has been proposed that every steam-user should be compelled to have his boiler examined and certified by some private association or company instituted for that object, and authorized by the Government. Others propose that insurance should be an essential accompaniment to this arrangement, and that, to secure the integrity of the service, the boiler-inspectors should themselves be inspected by the Government.

With regard to these propositions, the Committee would wish to express a strong and, as they think, a wholesome dread of any Government interference with the management of private concerns; and they cannot but consider that the plan proposed of handing over all the boilers in the country to the supervision of the Board of Trade would prove harassing to the steam-

user, and a barrier to progress. Such a system, it is thought, must soon prove a system of limitation. Inspectors armed with Governmental powers must be guided by a code of rules laid down by some higher and central authority. They must be instructed what diameter of boiler and what thickness of plate to allow for certain pressures of steam, also what area and description of safety-valves, and what number and description of fittings generally. Thus the responsibility of construction would be removed from the boiler-makers to the Government, and the Board of Trade would become the national boiler constructors. However wisely and liberally such a system might be worked, and however carefully its code of rules might be devised, it is feared it would shortly prove an irksome limitation, and that serious embarrassment would result. Whether any milder measures could be introduced to extend the operations of private associations, is a question on which the Committee are not in a position to pronounce an opinion at present; but the subject appears to them to be one of considerable importance, and the more public attention is called to it, and the more it is ventilated and discussed, the better.

The Committee would venture, however, to submit to consideration, whether it would not be worth while to try the effect of more searching coroners' investigations, and plain-speaking verdicts, before any other steps are taken. Were the course recommended herein with regard to coroners adopted, such a mass of well-authenticated information would soon be accumulated that it would be shortly apparent whether this measure were of itself sufficient to arrest the course of boiler explosions, or whether the recklessness of steam-users was so great that more stringent measures were absolutely necessary; while, supposing that the latter unfortunately proved to be the case, the amount of authentic information obtained would form a sure basis for legislative enactment. The Committee therefore venture to urge that the plan proposed in this Report be fairly tried before any further steps be taken, and they recommend this subject to the best consideration of this Meeting of the British Association.

It should not be omitted to mention that since the subject was brought under the consideration of the Mechanical Section of the British Association last year, the Manchester Steam-users' Association memorialized the Home Secretary with regard to the improvement of coroners' inquiries in the manner referred to in this Report. The deputation was favourably received, and the Home Secretary stated, in his place in the House of Commons, only a few days since, that he should endeavour, during the Recess, to prepare a measure for the prevention of steam-boiler explosions. Thus considerable attention has been drawn to this subject during the past year, and considerable progress has been made in educating public opinion with regard to it. The Committee think that this affords ground for congratulation, and that, from the interest now aroused in connexion with this subject, the attainment of the prevention of steam-boiler explosions is not far distant.

(Signed on behalf of the Committee)

WILLIAM FAIRBAIRN, *Chairman*.

August 18, 1869.

Preliminary Report of the Committee appointed for the determination of the Gases existing in Solution in Well-waters. By Dr. E. FRANKLAND, F.R.S., and HERBERT M'LEOD, F.C.S. (Reporter, HERBERT M'LEOD.)

IN consequence of the investigation being far from complete, this Report must be considered as merely a preliminary one; a more detailed account of the results obtained, and the inferences to be drawn from them, must be postponed till a future occasion.

The apparatus employed in these and other experiments was described at the last meeting of the Chemical Society, and has been published in the *Journal* *.

In collecting the waters it is, of course, of the greatest importance that they should be prevented from coming in contact with the air, otherwise serious errors might be produced in the determination of the gases dissolved. In order to avoid these errors, the tap delivering the water from the pumps is connected by means of a caoutchouc tube with a tubulure at the bottom of a tin cylinder, about 10 inches high and 7 in diameter. The water is turned on and allowed to flow over the edge of the vessel; thus only the surface of the water is exposed to the action of the air, and the liquid at the lower part of the vessel is protected by the upward current and continual overflow.

The bottles used for collecting the waters hold a little more than 100 cubic centimetres, and a separate quantity is used for each experiment. Into each bottle a piece of glass tube, bent in the form of a U, is introduced; one end of the tube is sealed, and in the closed limb a bubble of air is confined by mercury which fills the open limb and the bend. In the collection of each water, four of these bottles are lowered by means of pieces of string into the tin vessel, while the water is flowing over its edge. After being filled each bottle is carefully examined, and if any bubbles of gas adhere to the sides they must be removed. The bottles are then again lowered into the vessel and the temperature observed. A siphon is now passed to the bottom of one of the bottles, and after it has drawn two or three hundred cubic centimetres of water through the bottle, it is placed into the second. The first bottle is now raised, and while its neck is still under the water, a slightly greased stopper is put into the neck and carefully pressed down. This force compresses the air contained in the glass tube, and if the pressure is sufficient, it prevents the escape of gas from the water, a precaution which in some cases is very necessary. The siphon is then transferred from the second into the third bottle, and the second is closed and removed. When the four bottles have been filled, the stoppers are covered with ground caps. The caps are next filled with mercury through small holes at their tops, which are afterwards closed with glass stoppers.

The gases should be removed from the waters as soon after collection as possible. In the following cases, the greatest length of time which was allowed to elapse between these operations was five days, but usually the removal of the gases was effected the day after the collection.

With so few results as have been obtained up to the present, it will be impossible to do more than point out the small quantity of oxygen in the waters from deep wells as compared with those from shallow ones, and with rain- and river-waters. The quantity of nitrogen is also very remarkable, as being in all the cases, except the river- and rain-water, in excess of the

* *Journ. Chem. Soc. ser. 2. vol. vii. p. 307.*

	I. Rain-water.	II. Water from cistern of Royal College of Che- mistry. Supplied by Grand Junc- tion Company.	III. Water from well in chalk, 367 feet deep, at Messrs. Barelay and Perkins's Brew- ery, Southwark.	IV. Water from well not down to chalk, in course of construction. 143 feet deep, at Messrs. Barclay and Perkins's Brewery, South- wark.	V. Water from chalk well at Worth- ing.	VI. Water from surface well to face of the chalk, 27-30 feet deep, at Mr. Hills's Brewery, Deal. In the town. Influenced by tide.	VII. Water from chalk well, 115 feet deep. Water- works, Deal, sur- rounded by cul- tivated fields. Not influenced by tide.	VIII. Water from waterworks, Deal. Drawn from main about a mile from the reservoir.
Temperature at time of collection	13°·5 C.	14°·8	12°·1	12°	?	11°·9	14°·8	17°·2
Mean of	2 experiments.	2 experiments.	2 experiments.	4 experiments.	2 expts.	2 experiments.	2 experiments.	2 experiments.
Volumes of gases in 100 volumes of water.	1·382 0·673 0·135 — 2·190	1·397 0·620 4·239 — 6·256	2·030 0·029 5·765 — 7·824	1·573 0·018 3·514 — 5·505	1·532 0·446 5·432 — 7·430	1·704 0·023 10·232 — 11·979	1·543 0·380 5·055 — 7·183	2·241 0·795 4·413 — 7·450
Solubility of nitrogen in 100 volumes of distilled water (Bunsen)	1·468 at 15·5°	1·478 at 15°	1·549 at 12°	1·549 at 12°	.....	1·549 at 12°	1·478 at 15°	1·44 at 17°

The experimental results of which the above numbers are the means were tolerably concordant; the greatest differences between the results of different experiments are the following:—In water No. IV. exp. 3 gave 0·140 part more nitrogen than exp. 2. In water No. VII. the oxygen obtained in the second experiment was 0·045 in excess of the quantity obtained in the first. In water No. III. the second experiment gave 0·769 part more carbonic anhydride than the other. Since this last was done the modes of collection and removal of the gases have been improved.

amount absorbable by distilled water. To show this there is introduced into the foregoing Table numbers taken from Bunsen's 'Gasometry,' indicating the quantities of nitrogen absorbable by 100 volumes of distilled water at the temperatures which are nearest to those at which the waters were collected. The reasons of this apparent anomaly will be investigated during the course of the ensuing year, and it is hoped that, by the next Meeting of the Association, a much larger amount of information will have been obtained. The prosecution of the experiments has been much hindered by the necessity of perfecting the apparatus for the removal of the gases, and the means of collection, so that it was not until after the beginning of July that any systematic work could be commenced. Although the investigation will be continued, it is not intended to ask for any additional grant, as the amount voted last year will probably be sufficient.

The Pressure of Taxation on Real Property. By FREDERICK PURDY, Principal of the Statistical Department, Poor Law Board, and one of the Honorary Secretaries of the Statistical Society.

[A Communication ordered to be printed *in extenso* among the Reports.]

I. THE PRESSURE.

THE question of the fiscal pressure caused by the incidence of imperial and local taxation on real property is no new topic in this country. In 1846 the House of Lords appointed a select committee to inquire into the "Burdens affecting real property." This committee, of which Lord Beaumont was the chairman, gathered from various sources a large body of information, and made in the same session a rather brief report to the House upon the voluminous evidence which was subsequently published. A draft report which Lord Montague, one of the members, had drawn up was not accepted; it was, however, printed as a separate paper by the House of Commons in the same year.

Both documents have rather an historical than practical interest for us in the present day. Our imperial financial policy has materially changed since 1846, and the local burdens of that time are quite dwarfed in absolute amount by recent growths in the same field. It therefore appeared a useful task to ascertain the taxation laid on real property at this moment with the greatest precision that authentic records render possible. I propose to do this *statistically*; an *economic* treatment of the subject would be, no doubt, as touching the pockets of a large number of people, a more exciting theme. But admitting that the aggregate of imperial and local expenses must be provided for, throwing a tax off one description of property means, in the sphere of financial policy, placing it on another. The correlation of the parts would be disturbed; the wide and intricate field of taxation must then be entirely reviewed and readjusted, a task of no mean difficulty which may be fittingly omitted on this occasion.

The nearest approach, at present, to the annual value of real property in England and Wales is expressed by some figures supplied to me by the courtesy of Mr. Frederick Gripper, Accountant and Comptroller-General to the Board of Inland Revenue.

They show the gross sum to be upwards of £145,000,000 for the financial year 1867-68, thus assessed:—

	£
Under Schedule A	116,341,387
Sum formerly charged under A, but since 1865 transferred to Schedule D as profits	29,057,991
Total	145,399,378

The assessment upon which the Crown actually gathered the tax was upwards of £9,000,000 short of this gross sum, the statement of the amounts “charged” standing for the same year, thus:—

	£
Under Schedule A	107,092,692
Sum formerly charged under A, but since 1865 transferred to D as profits	29,041,932
Total	136,134,624

A difference between gross and net value of £9,000,000 and more, arising upon those properties which are still retained in Schedule A.

What originally stood in Schedule A before any transfer was effected can be shown in detail for the last year of the old series thus:—

Gross Annual Value of Property in England and Wales, Assessed under Schedule A of Income-Tax Acts, Year ended 5th April, 1865.

	£
1. Lands, including tithe-rent charge	46,403,000
2. Messuages	59,286,000
3. Tithes (not commuted)	58,000
4. Manors	180,000
5. Pines	106,000
6. Quarries	526,000
7. Mines	4,277,000
8. Iron-works	1,248,000
9. Fisheries	31,000
10. Canals	786,000
11. Railways	13,882,000
12. Gas-works	1,618,000
13. Other property*	2,486,000
14. General profits†	387,000
Total	131,343,000

The principal items now placed under Schedule D have that letter marked against the sum in the list above; probably considerable transfers have also been made from “other property” and “general profits;” but this is certain, quarries, mines, iron-works, canals, fisheries, railways, and gas-works heretofore under Schedule A are now accounted for under Schedule D.

In the British fiscal system real property suffers an exceptional liability to taxation. It bears fully *three-fourths* of our heavy and fast-increasing local rates, and then in a variety of ways it is made to supplement the imperial budgets. Here I may be permitted to remark that in this country we are too much in the habit of discussing our imperial and local systems of rates and taxes as things apart, yet their conjoint bearing on the interests of the holders of real property is obvious and practical. This opinion I had the honour of indicating to Section F, in a brief paper, when the British Association last met at Cambridge‡.

The amount of local taxation incident upon real property is now known

* Salt-springs or works, alum-mines or works, docks, drains and levels; rights of markets and fairs, tolls, bridges, and ferries.

† All other profits arising from lands, tenements, and hereditaments or heritages not in the actual possession of the party to be charged, and not before enumerated.

‡ See the Transactions of the British Association for 1862, p. 162.

with great fullness: much is also known of the imperial burden; but, for the reasons hereafter stated, approximate completeness is alone attainable in this section of our taxes. As the heaviest in amount the local taxes are first shown by the subjoined list:—

Local Taxation in England and Wales falling on Real Property in 1867-68, according to Mr. Ward Hunt's Return, Nos. 497 and 497—I. Sess. 1868.

	£
1. Amount levied under the name of poor-rate	11,061,000
2. County, hundred, borough police, <i>not</i> paid out of poor-rate	307,000
3. Highway-rate, <i>not</i> paid out of poor-rate	917,000
4. Church-rates	217,000
5. Lighting- and watching-rate	77,000
6. Improvement-commission rates	445,000
7. General district-rates, levied under the provision of Public Health and Local Government Acts	1,797,000
8. Rates under Courts of Commissioners of Sewers, including drainage and embankment rates	709,000
9. Rates of other kinds, and inclusive of £981,000 levied in the metropolitan district as general and lighting-rates.. }	1,203,000
Total.....	16,733,000

. Taken in round numbers and corrected by the most recent returns in possession of the Poor-Law Board.

It may be well to remember that nearly half of this heavy sum is entailed upon the ratepayers by the absolute right to relief which the legislation of England has given to the poor. The expenditure last year for "relief to the poor" was £7,498,000; but law charges to the amount of £29,000, the cost of making valuations £50,000, and "money expended for all other purposes" £532,000, a large portion of which latter sum is solely contingent on pauperism, are all items that are excluded from what, in official language, is termed "relief;" though it is patent that if pauperism ceased out of the land, most of these expenses would be determined. Add a due proportion of the excluded items and we may fairly say that, in round numbers, English pauperism last year cost little short of £8,000,000 sterling.

The imperial taxes that are incident upon realty certainly exceed £6,000,000; they probably approach to £7,000,000. So far as their respective amounts can be discovered, they are exhibited in the following statement:—

Imperial Taxation in England and Wales falling on Real Property in 1867-68, or thereabouts, according to Returns in possession of the Commissioners of Inland Revenue.

	£
1. Property-tax, 1867.....	2,354,000
2. Land-tax, 1868	1,058,000
3. House-duty, 1868	1,003,000
4. Succession-duty, average of 1867-68-69	562,000
5. Stamps on deeds and other instruments, not otherwise specified, 1868 (a)	1,405,000?
6. Fire insurance? .....	.....
7. Stamp-duty on wills and letters of administration? .....	.....
8. Probate Court fees? .....	.....

Approximate total 6,382,000

(a) Stamps on sales, conveyances, leases, mortgages, &c. will be included in this sum, but what portion is not incident on real estate it is impossible to discover. The stamp-duties on wills and letters of administration, some of which will be paid on leaseholds for years, and therefore indirectly from real property, are excluded from the above, and that exclusion may possibly balance the excess under the head of stamps on deeds. The duty

on wills &c. in England and Wales in 1867-68 was £1,493,000. Probate Court fee stamps, which in 1868 amounted to £124,000, are also excluded.

The succession-duty experiences considerable variations; according to particulars furnished by Mr. Gripper, the sums collected in England and Wales for the financial years 1867, 1868, 1869 were respectively £507,081, £608,297, and £571,831. For the purposes of this paper the average of the three years has been taken. Fire-insurance duty has ceased; it is noted above as a reminder; very recently it was a tax that largely bore on certain descriptions of real property. After trial it is found impossible to unravel the stamp-duties so as to exhibit that portion of the impost with which alone this paper is concerned.

Allowing for possible defects in the imperial tax table, the aggregate burden is this:—

	£
Taken by local taxation	16,733,000
„ imperial taxation	6,382,000
Grand total	23,115,000

upon the gross value assessed under Schedule A—£145,399,000. This is equivalent to 3s. 2½*d.* in the pound; on the net value (the amount “charged,” £136,135,000) it equals 3s. 4¾*d.* in the pound. Here, however, it should be remembered that the standards of comparison are themselves averages of a comprehensive sort; it is not every pound of gross or of “charged” value that is taxable. For example, on many estates the land-tax is redeemed*; the inhabited-house tax is not paid by more than *one-sixth* of all the householders of the kingdom; though measured on *value* alone, more than half the house-rental pays. The assessment of houses &c. (other than farm-houses) to the property-tax in 1864-65 was, as already stated, £59,286,000; but for the purposes of the house-tax, the levy was made upon £30,405,000. Again, many small proprietors, being outside the statutable limit of the income-tax, altogether escape it. In a word, as a taxable *corpus*, the valuations here cited must not be invested with an homogeneity they do not possess.

Though the Crown valuations under Schedule A be a much truer exponent of the country's wealth in real property than any assessment yet made for the purpose of local ratings, it is nevertheless advisable to give, in a theme of this kind, some attention to the latter.

There is no information in existence as to the “rateable value” of England and Wales previous to the year 1840-41. This “rateable,” or, as it is sometimes termed, “annual value,” when discovered from returns obtained by the Poor Law Commissioners from the overseers of that time, was found to be £62,540,000. The parish officers' valuations were notoriously defective. The annual value of real property was ascertained by the Commissioners of the Income- and Property-Tax Acts to be £85,803,000 in the subsequent year 1841-42. The whole excess of £23,000,000 or so must not, however, be ascribed to under valuation in the poor-rate assessment. Some few things are in Schedule A that are exempt from poor's rate. The Parochial Assessment Act of 1837 does not appear to have mended matters much†. The increase of assessable property, and, latterly, the application of sounder principles, introduced by the assessment committees in the practice of valuation, though yet very short of attainable completeness, make themselves visible in the next statement:—

* The annual tax redeemed up to 1856 was £770,000.—*Statistical Journal*, vol. xx.

† See ‘*Statistical Journal*,’ vol. xxiii. p. 292 *et seq.*

Parochial Years.	Poor-Rate Valuation.		
	Gross Estimated Rental.	Net Annual or Rateable Value.	Clear Interval between the Successive Returns.
1840-41	£ Not known.	£ 62,540,030	—
1846-47	"	67,320,587	6 years.
1849-50	"	67,700,153	2 "
1855-56	86,077,676	71,840,271	5 "
1865-66	110,079,308	93,638,403	9 "
1867-68	118,334,081	100,612,734	1 year.

A Parliamentary Return of some interest to the discussion of the incidence of taxation was in 1853 obtained upon the motion of Mr. Moffatt. The growth of the last fifteen or sixteen years has materially changed the relative proportion of some of the data selected from the paper and placed hereunder. Historically they have value now; hereafter, when we wish to ascertain whither political and economic forces are in this matter of taxation carrying us, their worth may be greater. The amounts payable in England and Wales out of each sort of rateable property was, in the language of the return, "ascertained by the rule of proportion applicable to the poor's rate."

Different Descriptions of Property upon which the Rates were Incident.	Poor's Rate (including County, Borough, and Police Rates).	Highway Rate.	Land-Tax.	Proportion paid by each Description of Property.	
				Amount.	Per cent.
1. Land, including farm-houses	£ 2,707,627	£ 607,546	£ 533,112	£ 3,848,285	41·2
2. Tithe-rent charge	205,056	59,123	60,563	414,742	4·4
3. Houses, including ware-houses, factories, &c. }	3,002,683	666,669	593,675	4,263,027	45·6
4. Coal-mines	3,124,526	889,574	478,816	4,492,916	48·1
5. Saleable underwoods	61,191	14,082	5,981	81,254	0·9
6. Canals	28,524	6,236	5,581	40,341	0·4
7. Railways	28,471	7,506	3,756	39,823	0·4
8. All other descriptions of property	204,871	52,537	30,171	287,579	3·1
Totals	102,032	25,881	12,937	140,850	1·5
	6,552,293	1,662,575	1,130,917	9,345,790	100·0

Note.—The poor-rate and highway-rate levy are for the year 1851-52; the land-tax for the previous year.

Here it is seen that sixteen years ago landed property, including the tithe-rent charge, bore 45·6 per cent. of the aggregate amount of the rates and tax mentioned above, and the residual property 54·4 per cent. There is not, I believe, any subsequent return to show what changes may have taken place in these ratios when measured on the basis of the poor-rate valuations; though, from the comparatively slow growth of one and the rapid growth of the other portion of assessable property, the differences must be considerable.

In the absence of a means of comparison similar in each particular with the table of 1851-52, we may, bearing in mind the necessary qualification, take the property-tax assessment for 1864-65 as a guide, especially as the

more ratios are much less open to doubt, from the diversity of practice between Crown valuers and local valuers, than the absolute amounts.

Amount and Ratio of Gross Assessment in 1864-65, of Lands and of other Real Property under Schedule A, in England and Wales.

	£	Per cent.
Of lands, including tithe-rent charge	46,403,437	35·3
Of all other descriptions of real property assessed in this schedule	81,938,062	64·7
Total	131,341,499	100·0

As against 1851-52, we may say that 10·3 per cent. has passed from the land and gone upon other assessable property. Land would appear now liable to bear rather more than *one-third* of any burden laid upon real property generally, and real property, other than land, rather less than *two-thirds*.

II. THE GROWTH OF THE PROPERTY UNDER PRESSURE.

It has thus been shown, I may submit, that the imposts upon real property are in appearance exceptionally severe, taxed as it is both by the imperial and the local assessor. Have these burdens in any wise injured or retarded the growth of this species of wealth? is the next question. During the past fifty years England has increased largely in numbers, and more largely in material prosperity. Under such conditions, it is inconceivable of any community that a great impetus should not have been given to the development of what English lawyers mean by the term "realty" or real estate. Authentic records afford the means of instituting a comparison between the years 1815 and 1868; or, roughly speaking, after the lapse of half a century. In the first-named year the population of England and Wales was 11,004,000; in 1865 it was 21,500,000, the increase being 96·2 per cent. In 1814-15, the real property assessed under Schedule A was £53,495,000, and in 1867-68 it was £145,399,000, or 171·8 per cent., and thus surpassing the rate of development in the population by 75·6 per cent.

This increase of real property is the more remarkable when the circumstances of what was formerly its most eminent constituent (land) are considered. This natural agent, in a country like England of the present century, is within very narrow limits restricted in quantity. Houses, mills, factories, railroads, &c. may and do increase indefinitely; arable land cannot. It is impossible to say what was the area under cultivation in 1815; and it is, I believe, a matter of conjecture which way the balance would incline if the loss by the expansion of our towns and by the introduction of railways was measured against the acquisitions by enclosures, which, reckoning only from 1845 to 1867, amounted to 506,502 acres, a surface much larger than the area now under cultivation in Dorset or in Cornwall. The estimated quantity of land occupied by a lineal mile of railway, according to a Parliamentary Paper of last Session, was 12·97 acres; the total extent 133,430 acres, or rather more than *one-fourth* of the quantity brought under culture by the Enclosure Commissioners in twenty-two years.

The Government has published no return of the gross valuation in each county, under Schedule A, for a period later than the financial year 1864-65; but since a comparison of the value of land and of the other descriptions of real property in that year, in the different parts of the kingdom, with the official account in 1814-15, may be of some interest to the Section, the details have been worked out and placed in an Appendix*.

* See 'Statistical Journal' for September 1869.

Taken divisionally, the results are these, for the aggregate of real property other than land:—

Divisions.	Annual Value of Real Property other than Lands*.			Increase per cent.
	1814-15.	1864-65.	Increase in 1864-65.	
	£	£	£	
I. The Metropolis and the extra metropolitan parts of Middlesex, Surrey, and Kent ..	6,914,492	31,336,856	24,422,364	353·2
II. South-Eastern, less the extra metropolitan parts of Surrey and Kent	921,408	3,215,947	2,294,539	249·1
III. South Midland, less the extra metropolitan part of Middlesex	664,948	2,475,068	1,810,120	272·2
IV. Eastern	1,032,175	2,453,107	1,420,932	137·6
V. South-Western	1,782,524	4,695,384	2,912,860	163·4
VI. West Midland	1,429,248	7,852,049	6,422,801	449·5
VII. North Midland	473,185	4,248,121	3,774,936	798·1
VIII. North-Western	1,856,841	13,138,535	11,281,694	607·6
IX. York	996,986	7,924,120	6,927,134	694·8
X. Northern	712,777	4,013,925	3,301,148	462·9
XI. Welsh	450,791	3,584,534	3,133,743	694·9
England and Wales	17,235,375	84,937,646	67,702,271	392·8

Under the house-tax the farmer's dwelling is separately assessed, but for property-tax purposes it is treated as an integral part of the land.

Divisions.	Annual Value of Lands (inclusive of Tithes).			Increase per cent.
	1814-15.	1864-65.	Increase in 1864-65.	
	£	£	£	
I. The Metropolis and the extra metropolitan parts of Middlesex, Surrey, and Kent ..	2,018,000	2,582,315	564,315	27·9
II. South-Eastern, less the extra metropolitan parts of Surrey and Kent	1,956,000	2,697,641	741,641	37·9
III. South Midland, less the extra metropolitan parts of Middlesex	3,716,000	4,935,099	1,219,099	32·8
IV. Eastern	3,209,000	4,908,096	1,699,096	52·9
V. South-Western	5,294,000	6,313,853	1,019,853	19·2
VI. West Midland	4,893,000	6,189,576	1,296,576	26·4
VII. North Midland	4,339,000	5,755,138	1,416,138	32·6
VIII. North-Western	2,397,000	2,826,389	429,389	17·9
IX. York	3,764,000	4,431,864	667,864	17·7
X. Northern	2,498,000	2,628,592	130,592	5·2
XI. Welsh	2,176,000	3,135,290	959,290	44·1
England and Wales	36,200,000	46,403,853	10,143,853	27·9

* With "lands," wherever mentioned in this paper, tithes in the earlier years, and tithe-rent charge in the later ones, are always included.

In these comparisons no adjustment for the depreciation of the currency in the earlier part of the century has been attempted. Professor Jevons has given a table in the 'Statistical Journal'* showing that, in 1814, gold was above the standard price of £3 17s. 10½*d.* by 34 per cent., and in the next year 20 per cent.; at the latter ratio *one-fifth* must be deducted from all values in 1814-15.

From the absence of any authentic record of the land under cultivation in 1814-15, the means of computing the farm rental per acre are wanting. We are in a better position now: the rent for the whole kingdom, as well as for individual counties, can be worked out with, I believe, a useful approach to accuracy. The rent for all England and Wales was, in 1866, £1 17s. 9*d.* per acre. The statistics for this, as well as for the counties of the south-western division, are displayed below.

	Total Area in Acres.	Acreage under all kinds of Crops, Bare Fallow, and Grass in 1866.	Annual Rental, Schedule B, in 1864-65.	Rent per Acre.
All England and Wales †	37,321,883	24,546,607	£ 46,403,853	£ s. d. 1 17 9
<i>South-Western Counties:</i>				
Wilts	865,002	636,786	1,161,656	1 16 6
Dorset	632,025	398,599	711,017	1 18 0
Devon	1,657,180	919,336	1,780,976	1 18 9
Cornwall	873,600	436,971	744,652	1 15 6
Somerset	1,017,220	735,604	1,852,522	2 10 4

Note.—The agricultural statistics do not include the area of hill-pastures: holdings under five acres are also excluded. In 1861, according to the census, there were 7656 holdings in England and Wales under five acres each; their aggregate area was, however, only 19,140.

These figures have, perhaps, no very immediate bearing on the subject of the paper; but it seemed of possible utility to record them here for future guidance.

While land and other kinds of real property have made, in the past half century, the highly satisfactory progress already mentioned, it is certain that trades, manufactures, and professions have enormously distanced agricultural industry in the race for wealth.

The assessment "for all profits or gains arising from any profession, trade, employment, or vocation," under Schedule D, is notoriously, and perhaps irremediably defective. In their last Report, the Commissioners of Inland Revenue estimate, from circumstances within their knowledge, that the return of income under this schedule is £57,250,000 short of the true amount; no exaggeration can, therefore, be charged against the figures which represent profits and gains in the annexed Table (p. 65).

The land rental in respect of which the farmer's profits are assessed has, during the fifty years ended with 1865, increased by £12,375,000, or 36 per cent.; the profits of trades and professions have, in the same interval, augmented by £72,611,000, or 212 per cent., irrespective of the correction due for depreciated currency in 1814-15. Two factors enter into the increased assessments returned under Schedules A and B since 1864—real

* Vol. xxviii. 1865.

† The rent per acre for land, &c. for 25,542,427 acres, under cultivation, in all England and Wales, according to the Returns of 1867-68, is £1 17s. 4*d.*

advance in quantity and in market value, and an apparent advance by better assessment*.

England and Wales under	Annual Value Assessed in	
	1814-15.	1864-65.
<i>Schedule B—</i>	£	£
Farmers' profits †	34,028,655	46,403,853
<i>Schedule D—</i>		
Profits of trades and professions	34,287,685	106,808,319

There is, I fear, no possibility of assigning the true value to each factor. The Union Assessment Committees' valuation of 408 unions, embracing about half the rateable property of the kingdom, in 1863 amounted to £43,298,000; in the following year, when it may be supposed these bodies had obtained greater knowledge of their work, the assessment of the same unions was raised £5,384,000, or 12·4 per cent.

III. CONCLUSION.

Though in the preceding pages the taxes incident upon real property have been termed a burden, this language requires some qualification when we examine the objects to which a large portion of our local rates are devoted. The charges entailed on the ratepayers by crime and pauperism might be dispensed with, to the great advantage of the property now defraying the cost, though English poor-rates largely supplement wages, and consumers thereby gain some temporary, but in its consequences more than doubtful, benefit. Expenditure upon the maintenance and repair of roads and bridges, upon the drainage and embankment of marsh lands, upon the sewerage, paving and lighting of towns, and upon many other services performed by improvement commissioners, as well as the sanitary measures undertaken by boards of health, are operations signally beneficial to rateable property.

So far, therefore, as the property is judiciously assessed, and the proceeds honestly and intelligently administered for these purposes, the local rate is a good investment, for which no enlightened owner will manifest an ignorant impatience of taxation. The imperial taxes and the other part of the local rates stand in a very different category.

[*Note.*—An Appendix, consisting of detailed Tables, will be found in the 'Journal of the Statistical Society' for September 1869.]

* Alluding, in 1864, to a new valuation of property then in progress, under the orders of the Inland Revenue Office, the Commissioners mention that in many districts the amount of duty was greater at 6*d.* than formerly at 7*d.* They state that, "so far as Schedules A and B are concerned, this result is attributable in no small degree to the care and judgment with which the assessments were made upon this occasion by our surveyors, acting under special instructions from this office. We have also been much assisted by the valuations under the Union Assessment Act, especially in the case of land in the occupation of the owner, where the former unsatisfactory parochial rating to the relief of the poor was the guide upon which our officers chiefly relied."—*Ninth Report of Commissioners*, 1865.

† Farmers' profits were estimated as equal to three-fourths of their rental in 1814-15, and one-half rental under the Act of 1842. The full rental of both years is given above.

On the Chemical Reactions of Light discovered by Professor Tyndall.
By Professor MORREN, of Marseilles.

[A communication ordered to be printed *in extenso* among the Reports.]

SINCE the last session of the British Association, Mr. Tyndall has published, in several papers, highly interesting researches on a particular species of luminous reactions, thus providing physicists and chemists with a new instrument, both of synthesis and analysis, to which he invites the attention and investigation of all whom it may concern. In obedience to this scientific challenge, I have repeated, with the utmost care, all the learned gentleman's experiments. I have found them all as rigorously exact as they are ably described. They refer to atomical evolutions in which we almost seem to detect Nature in her most mysterious operations. The molecules of bodies, when powerfully lighted, the observer himself being in absolute darkness, may be easily perceived in their infinitely minute motions; in following which, Mr. Tyndall, and every one who is passionately desirous of penetrating the secrets of the constitution of bodies, cannot but feel the most exciting curiosity. Mr. Tyndall has made use principally of electric light, and has caused it to act mostly on organic bodies. I have followed in this respect quite a different method and object.

Most favourably situated with respect to solar light, in Provence, where for months together we enjoy a cloudless sky, I proposed to limit myself to the use of solar rays only, and confine myself to those conditions which the atmosphere affords us. I have carefully avoided organic bodies, the molecules of which are highly complicated and most difficult to follow in their multifarious evolutions. I have even preferred the simpler bodies of mineral chemistry, as offering an easier field of observation to the physicist desirous of arriving at clear and precise results.

In this exposition I shall follow, step by step, the order which, without any preconceived or systematical ideas, directed my successive experiments. It is, so to say, a journey in an unknown land. I shall thus the better show the deceptions I met with, the incessantly supervening difficulties, the necessities of modifying the apparatus, and the various incidents of the route. I hope by this means the better to illustrate the object I had in view.

At the outset I made use of an experimental apparatus entirely similar to Mr. Tyndall's—a glass tube 8 to 9 centimetres in diameter and 1 metre long, fitted at each extremity into a broad brass ring luted with cement, and carefully ground in the anterior part; two plain pieces of plate glass, perfectly transparent, resting on the rings, and slightly lubricated on the edges with a fatty substance, constituted an air-tight cavity when a vacuum was formed. A glass cock, fitted on each extremity, and let into the cylindrical rings, allowed me to make the vacuum at one end, and to introduce at the other the gas or vapour on which the experiments were to be made. Extreme, if not absolute cleanness and perfectly dry tubes are indispensable requisites.

The light arrives in the tube after condensation by a lens which everything induces me to believe was not achromatic in Mr. Tyndall's experiments. In his apparatus, as in mine, two cones are formed joined at the apices, the first, the converging cone, with an orange-red periphery, the other, the diverging one, with a violet-blue periphery, circumstances which I notice here, because the white molecules which are about to appear will often assume, in passing through them, the hues of the luminous bands in which they circulate. When a vacuum has been produced in the tube, the light

passes through it without the cones being in the least perceived; the tube is optically vacuous; but when the gas or vapour is introduced, a blue cloud, or blue precipitate, of an incomparable delicacy appears after a varying lapse of time, first at the summit of the cones, then in the converging cone. As long as the precipitate is of that beautiful blue colour, the light which it sends to the eye is perfectly polarized as Mr. Tyndall has described it. Then by slow degrees the precipitate increases, and slowly becomes white, the light emitted still remaining polarized; but as the sides of the tube lighted by the cones send to the eye light which is also polarized, and as it were the product of a polarizer, the whitish vapour of the cones then behaves like a thin polarizing lamina under inspection through the Nicol held by the observer; and when the two polarization planes are perpendicular to one another, the whitish cones assume a magnificent blue colour, exactly as a thin lamina of selenite of the required thickness would do; but in proportion as the white precipitate increases, all polarization disappears. The precipitated molecules become heated, both at the summits of the cones and against the entrance glass plate, and there arises a motion, slow at first, which brings to the cones other particles of the body under experimentation, not yet acted on by the light; and as these particles, owing to transparency, appear dark, their intermingling with the white particles produces a series of the most beautiful, varying, and often most regular images, such as have been described with expressions of genuine admiration by Mr. Tyndall.

The precipitated molecules seem to increase in diameter, and the two cones are then resplendent with reflected light. But there are, for the eye, certain points where the cone takes a fine rosy colour; and the position of these points varies in the course of the same experiment. They are sometimes on a line which forms an angle of 45° with the axis of the converging cone, sometimes on a line forming an angle of $90^\circ + 45^\circ$ with the same axis. There is, as in the rainbow, a line of position, and for the precipitated molecules a zone of efficacious rays, which demand special and ulterior inquiries.

Let me resume the exposition of facts already so well described by the English physicist.

It will be easily seen that either a synthesis or a decomposition of a body has taken place, *i. e.* a new grouping of the atoms, when under the influence of concentrated solar light the blue cloud invades the cones.

The first body of which I have attempted the synthesis is that which I have so often and so easily obtained by electricity, by causing the induction spark to pass through a gaseous mixture, formed of one of oxygen, two of nitrogen, and three of sulphurous acid*. It is the compound which is formed in the leaden chambers in the preparation of sulphuric acid.

I submitted the gaseous mixture to the solar action immediately the compound was produced. The same gaseous mixture enabled me to recognize, like Mr. Tyndall, that the special rays which produce these reactions are neither the less refrangible calorific rays, nor the red rays even when highly concentrated. I have for this object made use of the greatest variety of screens—smoky quartz, iodine dissolved in bisulphide of carbon, CS_2 , then coloured glasses, red, orange, yellow, green; but I dislike and distrust the glass screens; I prefer by far liquid ones. The action produced was insignificant. It became, on the contrary, extremely energetic with blue and violet glasses.

It is therefore under the shock of the more rapid oscillations of the chemi-

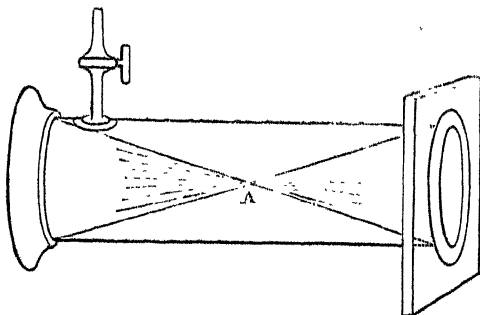
* *Vide Annales de Chimie et de Physique*, vol. vi. series 4.

cal rays that these reactions are produced. And here I wish to notice, in passing, an interesting fact, important especially for photographers—I mean the power of intercepting only the chemical rays of solar light, without stopping the luminous rays, possessed by a solution of bisulphate of quinine, well filtered and confined, by means of gutta percha, between two glass plates. This screen, 5 millimetres in thickness, is of an extreme transparency to light; but the chemical rays are intercepted. It might be advantageously used instead of the yellow glass, which, in photographic operations, casts on all objects such peculiar hues as to require a special education of the eye which has to judge of the reactions. This screen proved inestimable to me, as it allowed of my disposing and regulating the apparatus suitably beforehand, while it enabled me to permit the chemical rays, which the screen had intercepted, to act at the proper moment only.

After the experiments on $\text{NO}^2(\text{SO}^2)$ ($\text{O}=8$), I tried to unite the most resistant bodies. I introduced into the tube hydrogen and nitrogen perfectly pure and dry, and my surprise was extreme when I beheld the formation of a white cloud. This unexpected result, and one which I had considered as utterly impossible, obliged me to look still more closely into the matter, and to proceed with still greater caution.

The brass rings at the extremities of the tube were luted with the usual resinous cement. Against this cement my first scruples were now directed; it might still contain some volatile essence (spirits of turpentine for instance) which might have penetrated into the tube when a good vacuum was formed; and so small a quantity of matter sufficed perhaps to produce an appreciable result; this might have given rise to the unexpected cloud. It became necessary to suppress these rings and simplify the apparatus, which I effected in the following manner.

I took a cylindrical glass tube (a glass with a foot, Fr. *éprouvette*) 29 to 30 centimetres long and 8 to 9 in diameter, and 1200 to 2000 cubic centims. in capacity. The upper edge, somewhat bell-mouthed and carefully ground, of above 8 millims. thickness, was slightly lubricated with a little tallow, wax, and oil melted together. A flat square of plate glass, very transparent, was placed on the oil and sharply pressed down upon it, and some wax was melted all round the contact surface with a hot iron. At the bottom of the cylinder, on the side, a glass stop-cock was carefully fitted in. With this apparatus the vacuum may be preserved during a long time, even for months together. The



vacuum is produced, and the gases are introduced by the stopcock solely. But there is another method, very important to notice, for introducing into the tube the body to be examined, when it is solid or liquid and volatile. A very

small quantity of the substance is put into a very fine thin cylindrical tube, which is closed with the lamp at both ends after the introduction of the body, and can be, when necessary, easily broken to pieces by a slight shock against the tube. The mercury gas-holders which receive and conduct the gases are glass, carefully divided, so as to measure the volume of the gases experimented on. In lieu of an air-pump I have always made use of a mercury exhauster, the only apparatus which can be absolutely relied on, and which enables the operator, when the reaction is completed, to withdraw the gases from the tube for analysis; the mercury exhauster likewise enables us to measure the elastic force of the gases before and after the reaction, and thus indicates the variations of volume of the gas employed.

What therefore gives these experiments a peculiar character is the complete elimination of all gaseous vehicles employed to convey the vapour. The conditions of my experiments differ in this respect from Mr. Tyndall's.

The tubes, of smaller dimensions, which I have employed do not give indeed the splendid results which Mr. Tyndall presented to his delighted audience; but these tubes are easier to set up and to clean: the mercury exhauster possesses moreover another advantage; it allowed me to ascertain whether the gases were perfectly dry—a most essential point.

As to the means of conveying the solar light, the process was the following. A broad mirror receives and reflects horizontally a voluminous pencil of rays which is refracted by a lens 22 centimetres in diameter and of 40 centimetres focal length. The luminous cone is enclosed in a metallic box, whence it issues to penetrate into the tube through the glass plate. The summits of the two cones, the converging and the diverging, are situated pretty nearly in the centre of the tube (A); the two cones are therefore easily visible when the modifications of the bodies contained in the tube are produced. It must not be forgotten that the periphery of the two cones is coloured, as we said before, in consequence of the non-achromatism of the large condensing lens.

Under these circumstances I was very much surprised to see that a mixture of hydrogen and nitrogen, perfectly pure and dry, produced the reaction cloud. They had been dried by a very slow passage through pounded glass which had been calcined and moistened with sulphuric acid, pure and highly concentrated. I changed the desiccating substance, and successively made use of potash, chloride of calcium, phosphoric acid, all recently melted. In the three latter cases the cloud did not appear; the action was null, and the solar light passed unperceived. What could the *sulphuric* acid, then, convey? evidently some little *sulphurous* acid; for *sulphuric* acid is in fact a real emitter of it, and always adds a certain quantity of it to any pure gas which passes through it in minute and successive quantities; and this acts in fact as an absorbent of the dissolved gas. Therefore hydrogen and nitrogen cannot be united by solar influence when perfectly freed from other gases. But, in truth, what could the action of the sulphurous gas be?

I applied myself to a special study of sulphurous acid, and have ascertained how easy the decomposition of this gas is. As soon as the light passes through it, the white cloud appears; and if its manifestation is followed with care, it will easily be seen that it is produced not only at the summit of the cones, but likewise on the blue periphery of the first part of the diverging cone, and in the interior of the converging cone. I know of no body more sensible to luminous action; and the use of condensed light seems hardly necessary for the purpose, since the cloud is formed at other points than the summit of the cones. With this body it is certainly both easy and admirable to

behold the coloured bands which form the outline of the cones; and then even the violet rays (scarcely perceptible under ordinary circumstances) can be easily seen in the interior of the first cone. One may thus easily follow and account for the varied hues which the whitish vapour assumes when the variations of temperature waft it about the cones, intermingled with the black streaks arising from such portions of the gas as have not yet been acted on.

But to return to the sulphurous acid: What was the substance, blue at first, then whitish, thus obtained? The two hues so different were merely the consequence of a difference in diameter—the first hue belonging to the bodies (perhaps atoms) precipitated in the minutest state of division. The white and pearly colours appear when the diameter has sufficiently increased, and goes on still increasing. These circumstances induced me to endeavour to measure this diameter, a thing feasible by different means, but not with ease and facility by microscopic inspection, however; for the small spark-like bodies move too rapidly through the field of the microscope. But there were other methods. It may be first observed that if you expose sulphurous acid for a sufficient length of time to solar action, the precipitated substance becomes sufficiently abundant for a sort of haze to become perceptible in the tube. A part of the gas has been acted on; and the two luminous cones, when moved about in the tube, find everywhere reflecting precipitated molecules. If the tube is left long enough in repose and darkness, the cloud collapses, forms a deposit, and the gas is restored to its primitive transparency. If at this point the tube be again placed under solar action, the same successive phenomena of haze and return to transparency may be repeated indefinitely, till there remains no more gas to be decomposed, which is a very long process, for the very formation of the precipitate intercepts itself the chemical rays which form it.

But since transparency has been produced, a deposit of molecules must have taken place; and in this case, if the tube remains in a horizontal position and a broad slip of glass be placed inside it, it is on this slip that the molecules will be found. Their diameter might then be measured, either directly or by the rings of diffraction; but unfortunately it became impossible to use this expedient: the sulphur was dissolved by sulphuric acid; and instead of the molecules which I expected to find, very small drops only were perceived. But nevertheless it was possible to obtain the molecules of sulphur in large quantities, and to submit it to all requisite reactions so as to recognize it completely. It is sufficient to place in the tube after the sulphurous acid three or five cubic centimetres of distilled water; and after the solar rays have sufficiently acted on the gas, the tube is then shaken; the water dissolves the sulphuric acid and renders it powerless for dissolving the precipitated sulphur; the water then becomes milky and the sulphur is collected. It is then boiled in a small glass vessel (to drive out the sulphurous gas) and filtered in order to collect the sulphur; the water then gives abundant proof of the presence of sulphuric acid.

The atoms of the molecules of sulphurous acid are therefore not able to support the shock of the undulations of the chemical rays; they divide into

sulphur and sulphuric acid, $3\text{SO}^2 = \text{S} + 2\text{SO}^3$ (and from the form



they change to , in which state they are able to resist the shock of the chemical rays); but they exhibit other phenomena, to which I shall return

a little further on. During sixteen days of uninterrupted sunshine, from the 14th to the 31st of July, I exposed to solar light 1900 cubic centimetres of sulphurous acid in a tube of 2000 cubic centimetres capacity; and the decomposing action was, after that lapse of time, being still carried on in an always sensible and wonderful manner. It was evident that every day the solar action was only partial; it stopped as soon as the precipitated molecules of sulphur in motion in the tube were abundant enough to intercept all the chemical rays as an opaque screen.

The action of light on sulphuric acid was interesting to study; it is one of the most beautiful and instructive experiments which can be executed. It smokes abundantly on exposure to air; and this effect is attributed to the absorption of aqueous vapour by this substance. This is not a correct explanation, since in a perfectly dry vacuum the same phenomenon takes place. In the tube with a dry vacuum of $\frac{1}{2}$ to $\frac{1}{10}$ of a millimetre I had introduced a very fine thin tube containing anhydrous sulphuric acid. When I broke the tube, the little explosion, and certainly the great and sudden expansion of the substance, scattered about the vapour of the sulphuric acid, which, owing to the cold generated, was condensed into a white cloud, and appeared with a dazzling resplendency in the luminous cones. Here the chemical rays are powerless, they cannot destroy what they have produced. There is no more decomposition, but sulphuric acid is, if I may use the comparison, like water in the vesicular state in a cooled medium through which heat is about to penetrate. Insensible to the chemical rays, the sulphuric acid absorbs the calorific rays, on the contrary, with prodigious energy. This absorption is so perfect that all molecular motion ceases instantly. The molecules remain motionless, as if busy in absorbing the heat; and, as aqueous vapour does when heated, they pass into the state of a transparent gas, assuming previously to their apparent annihilation all the most magnificent hues. If during the operation the cock is rapidly opened and immediately closed, the great movement of molecules so rapidly and so energetically produced ceases at once, by the absorption of the heat.

This invisible vapour, when still further and sufficiently heated, will have its component atoms so shaken by the amplitude of their new oscillatory vibrations that they will be removed beyond the radius of their sphere of action, and the molecular edifice of sulphuric acid is (in its turn) destroyed.

I am afraid of fatiguing the attention of my hearers if I develope at a greater length the details of various experiments made with a large number of gases and vapours. We must stop here. Yet what results are to be noted!

Thus, for instance, in the most natural, perhaps, of all the groups that constitute the family of metalloids (that which comprises chlorine, bromine, iodine, fluorine) strange anomalies are observed. Chlorine and hydrogen unite under the action of chemical rays and form hydrochloric acid. The latter, either dry or humid, and prepared with pure crystals of mineral salt of chloride of sodium, cannot be decomposed by chemical rays of solar light; whereas hydriodic acid, on the contrary, can be decomposed; it is true (and this circumstance must not be overlooked) it is very difficult to procure this gas free from atmospheric air. A curious circumstance in the examination of hydriodic acid is, that the first shock of light frees part of the iodine, which appears with its peculiar violet hue at the summit of the cones, amidst the movements which destroy the molecular edifices—movements, perhaps, produced by the calorific rays only.

Bromine presents the peculiarity, that (as in the case of hydrogen with chlorine) if pure and dry hydrogen is introduced with a small quantity of

bromine into the little tube which is placed inside the cylinder previously to the experiment, and which is broken before it is submitted to solar action, after a few seconds the brownish colour of the bromine disappears and hydrobromic acid is formed, smoking abundantly on contact with atmospheric air.

I could increase still further the list of bodies submitted to this interesting means of investigation and experiment. I shall limit myself to a summary of the theoretical considerations which these facts have impressed on my mind.

We know that the calorific, luminous, and chemical rays are placed side by side and are even intermingled in the solar spectrum, with undulatory lengths successively decreasing.

Now all chemical bodies may be classed in two series: the first (having sulphurous acid for prototype) comprises all bodies formed under the action of calorific rays; the second (having hydrochloric acid for prototype) comprises all bodies formed by the chemical rays.

The following are the conclusions which the foregoing facts induce me to admit:—

If a body is formed and maintained under certain oscillatory conditions, the peculiar oscillations of the atoms which constitute its molecules must differ from those of the medium in which the body has been produced. But if this body is transferred into another medium in which it meets with oscillations isochronous to those of its own atoms, these oscillations increase, and the *vis viva* which the atoms acquire may become so great as to drive the atoms beyond the radius of their sphere of action; the atomic edifice is demolished; and as the constitutive atoms preserve, nevertheless, their peculiar affinities, they form a new edifice adapted to the oscillatory conditions in which they are now situated. Thus they escape the shocks of the generating medium, by ceasing to vibrate synchronously with it, exactly as an elastic sonorous body does not vibrate and gives no sound when the aerial vibrations which strike it are not synchronous with those which it is capable of reproducing. But if the new edifice is again submitted to the action of other synchronous rays it is again demolished.

Most curious evolutions! They seem to ask of the chemist:—

1°. Under what peculiar circumstances and influences are bodies formed?

2°. Under what vibrations precisely do their atoms oscillate?

3°. Finally, under the action of what other vibrations may the molecular edifice be destroyed?

Ozone, and all bodies capable of uniting themselves with other bodies, would be simply molecules whose atoms are possessed of a *vis viva* sufficient to animate and set in motion the atoms of the other bodies with which they unite themselves.

Will a *simple body*, even, always remain such to us, if it become possible to discover what oscillations have assembled the atoms of its constitutive molecule, and what can destroy it?

Such is the question which future lovers of nature and science may be one day enabled to solve.

One word more, upon a probable conjecture.

I have often seen that, under some circumstances not yet determined by me, the concentrated action of solar light is not without effect upon atmospheric air. In such case an appreciable whitish-blue colour is produced; might it not, then, be presumed that the fine whitish-blue vapour which in Alpine valleys bathes the foot of a mountain is produced by the action of a brightly luminous sky under favourable and unknown circumstances of heat, light, and aqueous vapour?

On Fossils obtained at Kiltorkan Quarry, Co. Kilkenny.

By WM. HELLIER BAILY, F.L.S., F.G.S.

THIS celebrated fossil locality, in the Upper Old Red Sandstone, is situated between Kilkenny and Waterford, about six miles south of Thomastown and a mile south-east of Ballyhale, on a ridge of Old-Red-Sandstone hills rising gently from beneath the Carboniferous Limestone plain to heights of from 400 to 500 feet above the sea-level, and sometimes to even 800 feet, as near the boundary of the parishes of Derrynahinch and Jerpoint West.

This quarry has been visited from time to time by private individuals, by the representatives of scientific societies in Dublin, and by the officers of the Geological Survey of Ireland, on all which occasions it has furnished some most interesting fossils, remarkable for their preservation and beauty, each time yielding specimens either new to science or such as would assist in elucidating those already collected.

At the meeting of this Association in Norwich last year, I advocated the importance of further excavations at this place, and applied for a grant of £40 towards that object; £20 was, however, the only amount voted. I felt some hesitation in accepting this sum in consequence of its insufficiency to carry out the extent of excavation I had intended; and had I not been aided by the Geological Survey, it would have been comparatively useless to attempt reopening this quarry with the sum placed at my disposal.

I did, however, proceed there last month, accompanied by an efficient and zealous assistant, Mr. A. McHenry, and provided with tools, such as bars and picks, for excavating with vigour. We were engaged for a fortnight, working most laboriously; and fortunately we had very favourable weather, except that it was extremely hot in this exposed situation for the heavy work we were occupied upon.

We engaged the services of two men, who ably assisted in removing the superficial soil and unproductive strata to the depth of about four or five feet, which was carted away at once; and we calculated that the total quantity removed in this manner and excavated by us amounted to at least 200 loads of stone and rubbish.

The character of the beds beneath this superficial covering, a fine-grained greenish sandstone, admitted of great facility in working, splitting up into layers, sometimes of large size; occasionally, however, it is much cut up by joints and small dislocations, which prevents its being worked so readily. Some of the surfaces of these layers are covered by plant-remains; and when first opened the fossils are most beautifully exhibited, as, from the dampness of the stone, their darker colour makes them appear very conspicuously.

The following is an enumeration of the fossil plants observed:—

Palaopteris Hibernica, originally named by Prof. Edward Forbes *Cyclopteris Hibernica*, then referred to *Adiantites* by Brongniart, and now placed by Prof. Schimper in his genus *Palaopteris*, the name signifying *ancient fern*, in allusion to the antiquity of its type and its first appearance with the most ancient terrestrial vegetables known, before the commencement of the Coal period*, that celebrated author on fossil plants observing that it differs from *Cyclopteris* in the arrangement of its leaflets &c., and from *Adiantides* (*Adiantites*) in its mode of fructification.

Two other ferns have been collected from this place; they are, however, of less frequent occurrence. One of these has already been brought before the notice of the members of this Association, and described by me as *Sphenopteris Hookeri*; the other, an undescribed species, I propose to name

* *Traité de Paléontologie Végétale &c.*, par W. Ph. Schimper. Paris, 1869.

Sphenopteris Humphresiana, after a gentleman (Mr. H. T. Humphreys) who worked most indefatigably at this quarry, from which he obtained a large collection of valuable specimens.

On our late visit we were fortunate enough to procure perhaps the finest specimen extant of *Pelecopteris Hibernica*, measuring about four feet in length, with its base of attachment and fertile pinnules shown at the lower portion.

A few fragments only of *Sphenopteris Hookeri* were collected; but we obtained a finer example of *S. Humphresiana* than any that had been before met with, being a branch or stem with several alternating pinnules arranged upon it.

Large closely fluted stems, which I had formerly regarded as being identical with *Sagenaria Veltheimiana*, and which, with others of a somewhat similar character, Dr. Haughton has described under the name of *Cyclostigma*, are also of frequent occurrence at this quarry: one of these stems measured six feet in length, with a diameter of six inches at its lower portion, and even then its commencement or termination could not be ascertained: the upper portion of this plant having divergent branches, was considered to be a distinct species, and referred to *Lepidodendron minutum*. Its fruit, of which we obtained remarkably fine specimens, is a cone-like body, formed of elongated scales, some of the detached ones showing very large and distinct sporules at their base; to these are appended long grass-like or linear leaves; it is remarkable, as Dr. Schimper observes, from the fact that no other species of *Lepidodendron* of which the fruits are known have such large sporules. That gentleman, through whom we sent a small collection of these fossils to the Museum d'Histoire Naturelle of Strasbourg, of which he is the Director, has done me the honour to name this remarkable plant after me, as he considers it distinct from *Sagenaria Veltheimiana*, especially in the form of the scales of the fruit, a part which I had not the opportunity of examining in the latter species.

Masses of roots with rootlets attached, such as I had observed in Mr. Humphreys's collection, and which he assured me were connected with the last-mentioned stem, were obtained by us from a bed which was permeated by fossils of this character.

The only example of mollusca found associated with these fossils, and of which we obtained good specimens, is the large bivalve named *Anadonta Jukesii* by Prof. Edw. Forbes, after the Director of our Survey in Ireland, whose loss, by death, we have had so lately to deplore. This shell is not unfrequent, and is so closely allied to the recent Swan Muschel, *Anadonta cygnea*, of our freshwater rivers, that it becomes a valuable auxiliary towards the presumption as to the freshwater origin of this deposit. It is, however, amongst the class Crustacea, especially that of the Eurypteride and Phyllopedæ, that the most important additions have been made to the list of organic remains from this locality by our late visit.

In one of the earliest collections of fossils made by the Geological Survey at this place, a specimen was obtained, portion of a thoracic or body-segment, ornamented with the peculiar scale-like markings characteristic of these crustacea: this specimen was labelled by the late Mr. Salter *Eurypterus? Forbesii*, with a query as to the genus. In the Journal of the Geological Society, vol. xv. p. 229, the same palæontologist, in a paper on some species of *Eurypterus*, alludes to this specimen, which he figures as being probably identical with *Eurypterus? Scouleri* (Hibbert), a Coal-measure species from near Glasgow.

We have since met with other portions which favours the belief that this specimen belongs to *Pterygotus* and not *Eurypterus*. Amongst the collection just made are two which appear to be heads, although they are not clearly defined; also a more definite but small example of the basal joint of a

swimming-foot (*ectognath*), showing very clearly the toothed edges of this masticatory and locomotive organ, another specimen being apparently the lower portion of a similar appendage. In a previous collection made by the Geological Survey are specimens showing the pincers or chelæ: in one of these the curved points of both rami are preserved; the upper one is seen to be armed with two large tooth-like projections; the lower one being imperfect does not show the corresponding parts.

It is possible all these fragments may belong to one species, which I propose to name *Pterygotus Hibernicus*. Another and distinct crustacean is shown in a well-marked head (or carapace), to which is attached portions of two of the thoracic segments. This specimen I fortunately picked up amongst the débris of the quarry immediately after visiting it. The form of this head, with its central arched divisions, to which the eyes are attached, is not very unlike that of a species of *Belinurus* from the Coal-measures; it is also provided with a border, and its posterior portion terminates on each side in a short spine. I have provisionally named this species *Belinurus? Kiltorkensis*.

Some detached body-segments, which were also procured at the same time in the progress of excavation (one of the specimens showing two entire segments, with portions of two others united), may possibly have belonged to the above species.

In a former collection from this place made by the Geological Survey, there are three well-defined examples of the detached carapace of a shrimp-like crustacean, which in shape approaches more nearly to that of the Silurian than to any of the Carboniferous species, and most nearly to *Hymenocaris* of the Lingula-beds. The anterior margin is broad and produced, giving it a curved outline, having a sinus running somewhat parallel and near to it, which is marked near the centre by a small elongated depression; the surfaces of these fossils are covered by fine labyrinthine markings. One of the fossils recently collected, although differing in shape (which may have arisen from pressure), is probably a carapace of the same species, it being also marked by a similar sculpturing. Some of the detached segments may also belong to this species, which, from its peculiar prow-shaped carapace, I propose to name *Proricaris MacHenrici*.

Of fish-remains we were not successful in obtaining many examples on this visit, a few detached scales only having been met with; those formerly collected are of great interest, and we had hoped to have met with specimens which might have thrown a better light upon some before collected; in this we were disappointed, but do not despair if another opportunity offers for a more extensive excavation. The fish-remains already obtained consist of large conical teeth, resembling those of *Dendrochus* or *Bothriolepis*, detached scales, and a large portion of a fish which appears to be identical with *Glyptolepis elegans*. The majority, however, appear to be referable to *Coccosteus*, some of them very closely resembling *C. decipiens*, Ag., especially a mass of plates in juxtaposition, showing the under sides; they consist, for the most part, of detached plates and jaws with teeth, which also resemble very much corresponding parts figured by Professor Agassiz in his Old-Red-Sandstone fish. There are also many detached smaller plates, and others with several plates united, which may possibly belong to *Pterichthys*: as some of the latter are in Prof. Huxley's hands, we may expect some valuable information about them.

With respect to the disposal of the specimens, a large number of which were collected, I would beg to suggest that the new species and those required for working out details, should be retained for the Geological Survey's collection in Ireland, and the duplicates distributed to such public institutions as it may be thought desirable to present them to.

Report of the Lunar Committee for Mapping the Surface of the Moon.

Drawn up by W. R. BIRT, at the request of the Committee, consisting of JAMES GLAISHER, F.R.S., Lord ROSSE, F.R.S., Sir J. HERSCHIEL, Bart., F.R.S., Professor PHILIPS, F.R.S., Rev. C. PRITCHARD, F.R.S., W. HUGGINS, F.R.S., W. R. GROVE, F.R.S., WARREN DE LA RUE, F.R.S., C. BROOKE, F.R.S., Rev. T. W. WEBB, F.R.A.S., HERR SCHMIDT, Admiral MANNERS, President of the Royal Astronomical Society, Lieut.-Col. STRANGE, F.R.S., and W. R. BIRT, F.R.A.S.

IN presenting the Report of the proceedings of the Lunar Committee re-appointed at Norwich, it is desirable to refer as briefly as possible to the progress of selenographical research during the entire existence of the Committee. Since the Meeting of the British Association at Birmingham four areas of the moon's surface, each of 5° in extent both of longitude and latitude, have been carefully and critically surveyed, not so much by the determinations of positions (the means at the disposal of the Committee being inadequate for instrumental and computative labour, which could only be carried on in an establishment exclusively devoted to such an object, the cost of which would far exceed the grants with which the Association has aided the work) as in an examination of the physical aspects of 100 square degrees of the moon's surface by means of the comparison and measurement of photograms, combined with observation at the telescope, by several observers in concert. Outlines of the objects thus surveyed have been laid down on the orthographical projection on a scale of 200 inches to the moon's diameter. The area thus surveyed includes 443 objects; a catalogue of these objects has been prepared containing numerous selenographical and selenological notices, those of the three areas completed previous to the re-appointment of the Committee having appeared in the Appendices to the Reports of 1866 and 1868.

One of the principal objects which has been kept steadily in view is such a description of lunar features that at any future time the similarity of the description with the state of any particular crater, mountain, &c., or a departure therefrom, may be readily ascertained. The great question of continued lunar change, either transient or permanent, as contrasted with apparent change dependent upon illuminating and visual angles, is one more likely for posterity to settle. If, in geological science, a region undergoing a series of changes (during the progress of which, through a long period of geological time, lakes have been drained, volcanoes have burst forth, extensive plateaus of igneous ejections formed, and vast denudations of softer materials effected) has retained its grander and more imposing features in their integrity, so in selenological science we may look for small, and in many cases to us almost inappreciable changes in and around well-recognized and imposing lunar forms, than expect to witness the obliteration of some very striking object as an evidence of change. The following are extracts from the catalogue of the area completed during the past year.

"The boundaries of *Hipparchus* differ materially from those of ordinary walled plains, and the cliffs on the S.W. are very unlike those of a circular form, inclosing large circular plains, as may be seen in the neighbouring formation *Ptolemæus*. They present the appearance of having suffered *erosion*, the character of the S.W. side of these cliffs being remarkably different from the exteriors of large rings, craters, and plains. These features, combined with the gradations of level observable in the floors of

Hipparchus, IV A¹¹, and the *Sinus Medii*, tend to invest them with peculiar interest. The apparent cutting away of the higher ground forming the E. slope of *Hind*, the projection beyond the general line of cliffs of the N.E. border of *Halley*, the indentations of the cliffs N.W. of *Halley* by the ravines scoring the E. slope of *Hind*, the general integrity of the cliffs S.E. of *Halley*, and the absence of similar indentations (these cliffs being cut through in one instance by a fault and in another scored by an apparent lava-channel) are phenomena which do not generally characterize walled plains. It is extremely difficult in the present state of our knowledge even to conjecture the kind of agencies which have operated in the production of a line of cliffs analogous in many respects to a terrestrial coast-line. One thing, however, appears to be certain, viz. the anterior existence of the E. slope of *Hind* as regards both *Halley* and the line of cliffs, while the fault and lava-channel on the S.E. are apparently more recent than the cliffs in which they occur."

"*HIND* is situated just W. of the fault IV A²³, IV A²², and occupies the highest point of the mountain-range IV A⁷. The slopes around it are of very different characters. On the S.E., E., and N.E. the exterior slope is grooved or furrowed with well-marked radiating valleys, while on the S.W. and N. the slope is uninterrupted and destitute of any radiating markings. The more recent production of *Hind*, as compared with the fault on the E., is indicated by the valleys on its flank cutting through the fault. The posteriority of the formation of *Halley*, as well as the production of the depression IV A²⁴ and the low floor of *Hipparchus*, is strongly suggested by the land on which the grooved valleys occur being penetrated by *Halley* on the one hand, and abruptly terminated on the other by the depression IV A²⁴ and the valley IV A¹⁷ on the S.E., and the cliff IV A¹⁶ forming the S.W. border of *Hipparchus* on the N.E. The remarkable smoothness of the floor of *Hipparchus* in close proximity with the cliffs is very significant."

"The slope of *Hind* on the S.E., E., and N.E., with its valley-like furrows and interrupted continuity by *Halley*, and the cliffs on the S.W. of *Hipparchus* before mentioned, may be advantageously compared with the crater *Aristillus* on the *Palus Nebularum*, which to all appearance now exists in its primeval state surrounded by its furrowed flanks, extending far on the surfaces both of the *Palus Nebularum* and the *Palus Putredinis*. Only a small portion of the flank of *Hind* remains, the outer portions having been cut off by the more recent formations. It is not a little remarkable that the cliff IV A¹⁶ should be so distinct and precipitous in the neighbourhood of a crater partly surrounded by the remnant of a furrowed slope; and it is difficult to conceive with such phenomena, that ejecta from a volcano such as *Hind* appears to be, should extend no further than so precipitous a cliff as the S.W. border of *Hipparchus*. The order of production appears to be as follows:—the fault on the ray from *Tycho*, *Hind*, *Halley*. It is probable that the production of the floor of *Hipparchus* occurred at a still later epoch. * * * The highest portion of the region in which *Hind* and *Halley* have been opened bears some resemblance to the granitic plateau of central France."

"A very strong indication of the protrusion of *Halley*, subsequent to the formation of the valley IV A²⁷, IV A¹⁷, and IV A¹³, supposing the three portions were once connected, is afforded by the valley being completely blocked on the N.N.E. and S.S.W. by the E.S.E. rim of *Halley*. Mr. Ingall, on June 26, 1866, pointed out to me the connexion of the valleys N.N.E. and S.S.W. of *Halley*. At first sight this connexion might appear to be in direction only. The valley IV A²⁷ is certainly closed, as appears on the

photograms, at the S.W. end by the angle formed by the N.E. border of *Halley*. The posteriority of the epoch of the valley IV A ζ ²⁷, IV A η ¹⁷, and IV A μ ¹³ to that of *Hind* is strongly indicated by the continuity of the S.E. slope of *Hind* being interrupted by the valley, much in the same way as the N.E. is by the cliff IV A η ¹⁶. We may trace here with great probability the following sequences of formations:—1^o, that of the high land IV A η ⁷; 2^o, the fault IV A η ²³, IV A β ⁶²; 3^o, the protrusion of *Hind*; 4^o, the formation of the valley IV A ζ ²⁷, IV A η ¹⁷, IV A μ ¹³ (several valleys hereabout are nearly parallel with this); 5^o, the formation of the cliff IV A η ¹⁶; 6^o, the protrusion of *Halley*; and 7^o, the cleft or wall on the E. of IV A η ², which is the highest in the locality.”

“The exactitude of direction of certain lines of valleys and mountains on opposite sides of *Hipparchus* indicate a more recent epoch for the formation of the floor of *Hipparchus* than for the production of the valleys and mountains on the lines specified. In connexion with these circumstances the following questions suggest themselves. Does the general parallelism of the lines of mountains and valleys in the neighbourhood of *Hipparchus* point to contemporaneity of origin? Has the present floor of *Hipparchus* resulted from a *subsidence*, by which the former surface was depressed below the surrounding levels? There are some indications that, prior to the production of the fault IV A η ¹¹, IV A β ²⁰, IV A γ ⁷², the surfaces E. and W. of it were at the same level. Was this the level at which the valleys and mountains above alluded to were continuous? and has the surface between them, as well as the floor of *Hipparchus*, generally become depressed below its former level? If so, it would appear that *Horrox* was opened upon this former irregular surface; and it may be interesting to inquire further as to what may have become of the portions of the mountains and valleys which have disappeared. This question may be very difficult to answer, especially in the very imperfect state of our selenographical knowledge.”

“There is some reason to believe that *Horrox* was not the only crater opened on this part of *Hipparchus* previous to the supposed epoch of depression. The curved mountain-chain IV A ζ ⁵⁸ presents all the characters of an ancient and nearly filled crater, slightly exceeding *Horrox* in size. Nearly half the ring is left, two craterlets are opened in the line of wall, and the surface which is traversed by a cleft is slightly depressed below the level of the surrounding floor of *Hipparchus*. It is one of those instances which Webb, in his paper on the Moon (*Fraser's Magazine*, Sept. 1868), refers to ‘of cavities in proximity to the grey plains having interiors so flat, so grey, so identical in appearance and level with the plain, that hardly a doubt remains of their having been subsequently filled up by intrusive matter of the same origin and under the same pressure as that around them.’ If IV A ζ ⁵⁸ be a nearly submerged crater, and the lines of mountains and valleys on opposite sides of *Hipparchus* were once continuous, the intermediate portions having also been submerged, the question to be resolved is—Whence came the material which has effected the submergence? The whole of the floor of *Hipparchus*, as compared with the surrounding formations, strongly exhibits indications of change of level; it is comparatively smooth, and of different reflective powers. The most striking difference of level occurs near the cliff IV A η ¹⁶ and the mountains IV A β ³⁸ and IV A β ¹⁷. Does this at all point to a subsidence of the floor of *Hipparchus*, accompanied by an invasion of intrusive matter? Instances of subsidence may be found on the moon; *Straight wall* may be quoted, the surface on the E. being at a lower level (about 1000 feet) than that on the W. The plain of *Dionysius* (Report Brit.

Assoc. 1865, p. 304) appears to be a *depressed* surface S. of the *cleft* of *Ariadneus*, the N. side being at a higher level. In like manner a portion of the surface N.E. of the line of cliffs from *Ptolemæus* to *Ritter* and *Sabine* may have subsided and produced the depressed region known as *Hipparchus*."

"While areas of depression, if not of subsidence, can be traced on the surface of the moon, and also the presence of a material which has invaded such regions and in many instances nearly buried preexisting craters and other objects, it is not so easy to ascertain whence this material came; still closer scrutiny is indispensable to throw further light upon it."

"In numerous portions of the moon's surface, as on that of the earth, we behold the results of the operation of two opposing forces,—one by which the features are moulded and, as it were, built up, imparting to the objects so produced an aspect of freshness that it is impossible to question their comparative recent production; the other by which objects once possessing all the characteristics of a recent formation have yielded, it may have been gradually, to surrounding influences, whatever they may have been, so that at the present time they exhibit the semblance of vast ruins, which in some localities are unrelieved by even the slightest indication of the operation of a force of an opposite character."

"Webb, in his very masterly paper on the Moon, in 'Fraser's Magazine' for September 1868, speaks of the possibility that the colossal lunar formations may have been the result of forces acting in a more gradual manner and with less temporary vehemence than may seem to comport with the term *explosion*. It may be that astronomers may have paid much more attention to those lunar features which are clearly the results of explosive action than to those which manifest the presence of a degrading agency. It has been considered that many of the larger forms have been produced by rapid, violent, and tumultuary processes; and, however true this view may be, it is certainly inadequate to account for the present appearances of still larger tracts in which no explosive outburst of an epoch which may in any sense be called recent occurs. Nearly filled as well as broken rings, interrupted mountain-chains, and comparatively smooth tracts without any well-defined boundaries are characteristic of such regions; and it may be asked in what manner and by what agency have they attained their present condition? Has the 'erosion' of Chacornac destroyed the missing portions of the broken rings? and has this 'erosion' acted suddenly or *gradually*? Has the 'diluvial,' restricted by Webb to the expression of comparative fluidity, independent of the nature of the material, invaded and nearly filled previously *deep* craters, so as to furnish a connected series of well-known forms, from the smooth, floored, walled plain to the just perceptible ring above the surface? Has this same 'diluvial' buried the lower portions and the lateral spurs of continuous mountain-chains, so that now the higher portions alone remain as short and detached ranges in the original line? One cannot help contrasting the continental region, to use a terrestrial analogy, in which this area IV A" occurs, with the magnificent chains of the *Apennines* and *Hæmus*, and the lower and smooth levels of the *Mare Imbrium* and *Mare Serenitatis*, as exhibiting in a very marked degree the results of the forces already mentioned. In the latter we see the effects of comparative *recent* action in the production of vast mountain-chains and the neighbouring extensive level plains. In the former these grand features are wanting; the surface, although far from being smooth as that of the *Maria*, is roughened only with the remains of former mountains, rings, and craters; the degrading agency, whatever it may have been, appears to have operated almost unchecked in

this region, and it is a subject of interesting inquiry as to how this state of things has been effected. Has the filling up, has the wearing down, if such is the case, been gradual? and what forces have been concerned in producing the mutilated forms we now observe?"

"Brightness and colour may ultimately become keys by means of which a better acquaintance may be obtained with the chronological sequence of lunar formations. Chacornac refers the great continental formations to an epoch anterior to that of the production of the great plains, this, again, being anterior to the period of explosive energy, contributing to the existence of numerous objects, such as bowl-shaped craters and smaller blow-holes, within the interior of which no intrusive matter is found. Reference, however, is not prominently made to objects in mountainous regions similar to those which we find in various portions of the great plains, viz. partly buried craters and partially destroyed rings, of which we have evidence in this and adjoining areas to the W. The contrast of the general colour of the surface hereabout, as compared with that of the grey plains, its mottled and rugged aspect, arising probably from its altered character from that which it possessed at a still earlier epoch, the absence of that sharpness of outline in its remaining mountain-peaks or ranges so characteristic of those which we find nearer to and often on the grey plains, together testify to a much earlier epoch than even that of the production of the partly filled rings on the grey plains. Bright, white, glistening surfaces, more or less in the neighbourhood of bowl-shaped craters, and dark patches of deep grey approaching black, appear alike to indicate the most recent formations—the first, it may be, from loose fragmentary incoherent materials ejected from adjacent craters; the last from substances in a state at least of comparative fluidity, which have escaped from the interior reservoirs at the times of eruption. Phillips compares the bright glistening region of *Aristarchus* to one in which *white* trachyte abounds; and many of the basalts in terrestrial volcanic regions present a dark colour. Between the brightest and darkest of such limited areas on the moon's surface every gradation of intermediate tint occurs; and from a careful consideration of the physical aspect of those regions which, on the one hand, reflect considerably less light than the brighter, and on the other considerably more than the darker, it may be inferred that such regions are amongst the most ancient of lunar formations."

A very ancient formation has been traced on area IV Aⁿ, the earliest state of which is considered to have been very similar to many of the more recent districts, such as those in which perfect craters and mountainous regions intermingle. The first change which appears to have taken place on this formation is that of the production of a grey plain, traces of which still exist. The material of this plain appears to have invaded certain craters, breaking down the walls of those immediately facing the plain, and partially filling others. The next change appears to have been of an elevatory character, the evidences consisting of a line of low mountains which has in a great measure obliterated the characteristics of a grey plain and introduced those more in accordance with an ancient district, which are strikingly in contrast with the features of the more recent craters to the E. The only instance of volcanic outburst on this ancient district consists of a chain of craterlets of quite an insignificant character.

The determination of the successive changes before alluded to rests on the strong indications, afforded by the careful study of photograms, of the priority and posteriority of well-marked features, which can only be realized by contemplating the lunar picture in the seclusion of the study. While the

telescopic view is far superior to the photographic, the continual changes of illuminating and visual angle prevent that appreciation of the relations of different features to certain epochs of production which can be so well studied in the photogram; the detail thus seized upon by the aid of photography is vividly realized by the eye at the telescope when the surface of the moon is suitably illuminated.

While engaged upon area IV A⁷ I have met with a remarkable instance of difference between De La Rue's photogram, Feb. 22, 1858, and Rutherford's, March 6, 1865. Lohrmann figures a plain, bounded on the W. by a mountain-chain on which he gives a little crater, which he numbers 51. In De La Rue's photogram the crater, which appears to be shallow, is *exactly* in the position given by Lohrmann. *Not a vestige of this crater is to be discerned on Rutherford's photogram seven years later!* Both photograms are under nearly the same illumination.

I have also met with a few instances of apparent variations of tint and brightness. The floor of the crater *Hind*, on the S.W. of *Hipparchus*, appears to have undergone a variability of tint during a period of eleven years according to the following numbers:—

$$1858.14 = 5^{\circ}.9, \quad 1865.18 = 7^{\circ}.0, \quad 1868.98 = 3^{\circ}.6$$

The slopes of two valleys, IV A⁷ 6 and IV A⁷ 11, which cut through the S.W. border of *Hipparchus*, manifest different degrees of brilliancy on the two photograms. They are much brighter on Rutherford's than on De La Rue's photogram, and IV A⁷ 6 appears to have become brighter in a greater degree than IV A⁷ 11.

		IV A ⁷ 6.	IV A ⁷ 11.
De La Rue	 1858.14	4.6	4.8
Rutherford	 1865.18	7.4	7.0

A crater, IV A⁸ 19, the middle of three conspicuous craters W. of *Hipparchus*, marked E Sec. I. Lohrmann and G by Beer and Mädler, appears to have become brighter since 1858. The gradations are exhibited below:—

Beer and Mädler..	1831-34	= 7.00	.. Full moon.
De La Rue	 1858.14	= 6.30	.. Terminator just past Copernicus.
Rutherford	 1865.18	= 7.14	.. " " "
Birt	 1868.98	= 7.56	.. " " "
Birt	 1868.99	= 8.00	.. 6 ^h 30 ^m past full moon.

The number of objects on the moon's surface, registered in accordance with the plan proposed in 1865 (see Report, 1865, pp. 294-299), is as follows:—

781	on	135	areas in Quadrant	I.
354	"	86	" "	II.
227	"	59	" "	III.
737	"	63	" "	IV.
Total	 2099	343	,, on the moon's surface.	

Of these, 769 only have been published, viz. 492 in the Reports of this Committee, and 277 in Mr. Birt's Monogram of the 'Mare Serenitatis.'

Report of the Committee on the Chemical Nature of Cast Iron. The Committee consists of F. A. ABEL, F.R.S., D. FORBES, F.R.S., and A. MATTHIESSEN, F.R.S.

THE Committee have to report that, during the past year, some material progress has been made in this research. They entrusted the preparation of the pure iron to Mr. Matthiessen, who carried out this part of the investigation in conjunction with Mr. Prus Szczepanowski. From a series of experiments, which are detailed in the Appendix, pure iron appears to be obtainable in considerable quantities, and we hope, if the Committee be re-appointed, that next year a great deal of valuable information will be obtained on the chemical nature and physical properties of pure iron and its alloys. The iron obtained by the process described in the Appendix is almost absolutely pure, containing only a minute trace of sulphur. According to an analysis made by Prof. Abel, the iron contained, in a hundred parts, only 0·00025 part of sulphur. In another analysis, the amount of sulphur found by Mr. Prus Szczepanowski amounted to 0·0007 per cent.* Phosphorus and silicon were carefully tested for by both analysts, and found to be entirely absent.

With regard to the physical properties of pure iron, owing to the want of time, nothing as yet has been accurately determined. It appears, however, that many of the physical properties of the pure metal differ considerably from those of the commercial.

APPENDIX.

On the Preparation of Pure Iron. By A. MATTHIESSEN, F.R.S., and S. PRUS SZCZEPANOWSKI.

After numerous trials, the general outline of which was given in the Report of last year, the following method was found to yield nearly absolutely pure iron, in quantities sufficient for the purpose of this research. Pure dried ferrous sulphate and pure dried sodium sulphate are mixed in nearly equal proportions, and introduced gradually into a red-hot platinum crucible. The mass is kept in fusion until the evolution of sulphurous acid gas ceases. The crucible is then allowed to cool, and the fused mass extracted with water. If the heat be properly regulated, the whole of the iron is left as a very fine crystalline oxide. This oxide is thoroughly washed by decantation to remove every trace of the sodium sulphate, and, after being dried, is reduced by hydrogen in a platinum crucible; the spongy iron thus obtained is then pressed into solid buttons and melted in lime crucibles with the oxyhydrogen-blowpipe.

Before proceeding further, it will be as well to mention the precautions observed in obtaining the raw material in the purest state. The commercial pure ferrous sulphate was freed from every trace of copper by leading sulphuretted hydrogen through the warm acetic acid solution. After filtration, the ferrous sulphate was twice recrystallized and dried, first in a water-bath, then in an air-bath. The commercial crystallized sodium sulphate was recrystallized several times to get rid of the last traces of chloride of sodium, and then heated on a water-bath to melt the crystals. As is well known, anhydrous sodium sulphate separates out from this solution, which was scooped out from time to time, dried on an air-bath, and powdered. The purification of the sodium sulphate from chloride of sodium was found to be necessary, owing to the fact that, when fusions were made with sodium sul-

* The amount of substance taken for each analysis was about 30 grammes.

phate containing that salt, the resulting oxide of iron always contained platinum. The hydrogen used for the reduction of the iron, as well as for the blowpipe, was prepared by the action of sulphuric acid on zinc, and purified by leading the gas through two wash-bottles, the first containing nitrate of silver and strong nitric acid, and the second caustic soda and acetate of lead, both bottles being half filled with pieces of pumicestone. The oxygen was prepared by heating a mixture of chlorate of potassium with 15–20 per cent. of black oxide of manganese, and washed by leading through caustic soda. All wash-bottle &c. connexions were made of glass, lead, or pure india-rubber tubing.

The fusion took place in a large platinum crucible (the contents of which was rather more than half a litre), enclosed in the usual manner in a clay crucible. The dimensions were such that about a kilogramme and a half of the mixture could be fused at each operation. After fusion the crucible is allowed to cool, it is then boiled out with distilled water, and the accumulated product of 6–8 fusions washed by decantation with boiling distilled water. The crystalline oxide settles very quickly, and thus allows of a very rapid and thorough washing. The washing was in every case continued several times after the wash-waters ceased to give any turbidity with barium nitrate*. The reduction of the oxide thus formed was made in a covered platinum crucible, heated by means of a large Bunsen burner. The hydrogen was introduced by means of a platinum-tube, reaching through the cover to the bottom of the crucible. The gas, purified as described above and dried by chloride of calcium, was always kept slightly in excess, a constant stream of gas being obtained by not using a generator, but two large gas-holders joined together, the contents of each being about 600 litres (20 cubic feet), two other gas-holders of similar capacity being used for the storage of the oxygen, the one being used to collect the gas from the retort, the other to contain the gas purified by passing through a strong solution of caustic soda.

The resulting spongy iron was pressed into solid buttons by means of a strong coining-press and a diamond mortar, the cylinder of which being about 70 millimetres in height; the iron, when pressed, forms a cylinder of about 15 millimetres in height, and weighs about 20 grammes. The melting of the compressed iron took place in lime-crucibles, the lime having been previously burnt, slacked, and reburnt, thus forming a fine impalpable powder, which was compressed in the crucible mould.

The best method of fusion was found to be as follows:—The lime-crucible was placed in a slanting position on a piece of lime. One of the oxyhydrogen-blowpipes, used in the process, played on the outside of the crucible whilst the flame of the other was directed inside. When white-hot, a cylinder of the compressed iron was thrown into it. It quickly melts, but at the expense of a large quantity of the iron which is oxidized. The amount lost by oxidation varies between 25 and 50 per cent. In order to obtain a good solid button of melted iron, it is necessary to cool it in an atmosphere of hydrogen, which is easily obtained, simply by turning off the oxygen from the blowpipe playing inside the crucible. The button thus obtained weighs about 15 grammes. On analysis, it was found that these buttons were free from phosphorus, silicon, and calcium, but contained a minute trace of sulphur.

The preparation, on a large scale, of the pure ferrous sulphate and sodium

* It is worthy of mention that the above process to procure pure oxide from the mixture of mixed sulphates yields the purest oxide we have as yet obtained.

sulphate was kindly undertaken for us by Mr. J. Williams, who prepared for us more than a hundredweight of each of these substances. We are also indebted to Mr. W. G. Underhay for the use of his large coining-press for the pressing of the lime-crucibles and the iron buttons.

Report of the Committee appointed to explore the Marine Fauna and Flora of the South Coast of Devon and Cornwall.—No. 3. *Consisting of* SPENCE BATE, F.R.S., T. CORNISH, JONATHAN COUCH, F.L.S., J. GWYN JEFFREYS, F.R.S., and J. BROOKING ROWE, F.L.S. *Reporter, C. SPENCE BATE.*

IN presenting to the Association the Third Report on the Fauna and Flora of the Southern Coast of Devon and Cornwall, I have to state that, independently of endeavouring to obtain a complete registration of all the more rare forms of life that exist upon the coast-line within dredging distance of the shore, the Committee have, as far as practicable, endeavoured to obtain information relative to the development, growth, and habits of those animals of which our knowledge has hitherto been imperfect.

CETACEA.

I think it desirable to put on record the Cetacea that have been taken within the last few years on the coast, specimens of most of which are preserved in the Museum of the Plymouth Institution.

Delphinus delphis. Dolphin.

Occasionally in the Channel: the last, January 1864. From the immense mass of fat underlying the skin, and from some unknown reason causing the skin to shrink, it was found impossible to preserve it.

D. tursio. Bottlenose Dolphin.

No record of any since the one described by Montagu in 1814.

Phocaena communis. Porpoise.

Common.

P. orca. Grampus.

Occasionally in the Channel. In Mr. Ross's collection, now in the Exeter Museum, I believe, was a young one driven on shore at Exmouth in 1844. The specimen in the Museum of the Plymouth Institution has been taken since.

P. melas. Round-headed Porpoise.

One captured off Plymouth in April 1839, and towed into the harbour.

Physeter macrocephalus. Spermaceti Whale.

One is stated by Bellamy to have been thrown on shore near Plymouth many years since.

Balenoptera boops.

This species has occurred several times. One in 1831 (the specimen now in the British Museum) was found floating off the Eddystone; a second was captured in a herring-net in Torbay, in 1846. In 1863 one was obtained off Plymouth, and the skeleton was purchased by the Alexandra Park Company, and is now, I suppose, at Muswell Hill.

Beluga albicans.

Mr. P. H. Gosse writes:—"On August 5th, 1832, I was returning from Newfoundland to England, and was sailing up the British Channel close to the land, when just off Berry Head I saw under the ship's bows a large

Cetacean of a milky-white hue, but appearing slightly tinged with green from the intervening stratum of clear water. It was about 16 feet long, with a round bluff head. It continued to swim along before the vessel's head, a few yards beneath the surface, for about ten minutes, maintaining our rate of speed, which was five knots an hour, all which time I enjoyed from the bowsprit a very good view of it. It could have been no other than the White Whale, the *B. borealis* of Lesson."

It frequently occurs on the Scottish coast.

FISH.

Of the Fish there have been but few novelties that I can add to the previous lists. The most interesting specimens are those of a Double-spined Ray and a variety of the Short-finned Tunny; the former is preserved in the Museum of the Plymouth Institution, and the latter in that of the Natural-History Society of Penzance. The Ray was taken off Plymouth, and appears to coincide nearly with that of *Raia aquila* (L.), except in being very much larger, and in the presence of two spines.

One point of interest that belongs to this specimen is the relation that it bears to *R. attavella* (L.). Of this Mr. J. Couch says:—"Consulting Artedi, and after him Linnæus, and comparing them with Lacépède, I find generally, as characters common to *R. aquila* and *R. attavella*, the body smooth and a slender tail. Linnæus says *R. attavella* has two spines often; but Lacépède makes the same remark of *R. aquila*. The material difference is that *R. aquila* has a very long tail, while *attavella* has it even less than the length of half the body. According to Lacépède (who says nothing of a Short-tailed Eagle Ray), the pectorals of his *aquila* are gradually slender, like the wing of an Eagle; but Artedi says that in *attavella* the pectorals are broad."

The dimensions of the recent specimen are 2 ft. 4 in. across the fins, 1 ft. 10 in. from the snout to the base of the spines, and 2 ft. 10 in. from the snout to the extremity of the tail; while those of *R. aquila*, in the Museum of the Plymouth Institution, are 14 in. across the fins, 11½ in. to the base of spines, and 2 ft. 1 in. from the snout to the extremity of the tail.

Of the Tunny (*Thynnus brachypterus*), or Short-finned Tunny, Mr. Thomas Cornish of Penzance says that the specimen that he captured in Mount's Bay differs from that given, both in figure and letterpress, vol. iv. Appendix, by Mr. Couch, in his work on British Fishes, in having "more fin-rays in the first dorsal than my specimen had, and does not show two free soft fin-rays between the first and second dorsals, which were conspicuous in my fish."

CRUSTACEA.

I am not aware that there are any novel forms or species to be recorded as the result of the dredging-operations of the Committee since the last reported list of Crustacea. In fact, the Committee have thought that they would be doing more to advance our knowledge of this class of animals, in pursuing the life-history of those that are already known to us, than by searching for the few stray specimens that have not hitherto been described as inhabitants of these seas.

Mr. Cornish informs me that he has very recently obtained in Mount's Bay several specimens of *Polybius Henslowii*.

Stenorhynchus phalangium.

The young of *Stenorhynchus* is a true Zoë, but differs from the typical form in the absence of the great rostral spine, and in the increased length of the great dorsal spine, by a series of latero-dorsal spines on the three posterior

somites of the pleon, and in the enormous development of two deciduous spines on the base of second pair of antennæ.

Homarus marinus.

Common as the European Lobster is, it is very remarkable that a very young specimen has, as far as I know, never been met with. I have for several years offered a reward for a very small specimen, but have never received one less than 3 inches long from the rostrum to the telson. Many years since Erdl, in a memoir on the subject, described the young *Homarus* as being hatched in the form of the adult animal.

I have, during the last two summers that I have been engaged on this Report, endeavoured to hatch and develop this among other forms. Having specimens brought to me with ova, I have succeeded in hatching the same; but the mystery connected with the preservation of life, so as to enable us to watch the development of the animal from one stage to the next, has yet to be overcome.

Through the kindness of Mr. Alford Lloyd, curator of the aquarium in the Zoological Gardens at Hamburg, I have been enabled to obtain a specimen hatched under his knowledge about eight days old. This enables me to prove that not only is the young hatched in a form distinct from that of the parent, but, while it has continued to increase in size, and therefore cast more than a single moult, that it retains that form for some time after its birth. The ovum is about one-tenth of an inch in diameter, and contains a vitellus of a dark, almost black, green colour. In the earlier stages of the development of the embryo, the central or deciduous eye is distinctly seen, but appears to be lost at the time of the escape of the larva from the egg-case; at this period the young animal has a short pointed rostrum, that at first is bent back under the ventral surface of the cephalon; two large eyes, which at first are bent under the lateral margin of the cephalon; two pairs of short antennæ; a non-appendiculated mandible; two pairs of maxillæ, the third pair or maxilliped being not yet developed; seven pairs of pereopoda, each of which carries attached to the third joint a long secondary multiarticulated ramus. The third pair is developed into a strong chelate organ, whilst the fourth and fifth pairs have rudimentary processes attached to the distal extremity of the fifth joint that demonstrates their chelate conditions at a very early stage. The pleon consists of six somites only, neither of which is furnished with a pair of appendages, or, as far as I could see, the rudiments of them. The posterior somite or telson is dorsally and ventrally flattened, evenly excavate at the posterior margin, which has the lateral extremities produced to a sharp point; while a large strong spine projects posteriorly from the centre, on each side of which, between it and the lateral point, are about twelve short stout pointed hairs.

Orangon vulgaris.

The young of the common Shrimp, although I have read of its resemblance to that of *A. mysis*, has not, I am convinced from that description, ever been described from the form in which it appears at the period when it leaves the egg-case.

At this stage it has a long straight anteriorly projecting rostrum on the carapace, a posteriorly projecting dorsal spine on the third somite of the pleon, and a lateral one on the posterior margin on each side of the fifth somite. The eyes are large, the antennæ short; the mandibles and two pairs of maxillæ, as well as the three anterior pairs of pereopoda, are alone developed, of which the three last are furnished with secondary appen-

dages: at a later stage in the development the posterior pairs of pereopoda are developed with secondary appendages like the Lobster in its primary stage. At this time the resemblance to some of the *Mysidæ* is so great that it is highly probable that some of those *Mysidæ* that are distinguished by the development of their appendages in the form of true legs may be only the young of the several species of *Crangon*.

Palaemon.

The larva of the common Prawn differs but little from that of the Shrimp in the early stages of its development. The chief points of distinction are only such as could be called specific, and not improbably may be found in the young condition of the larva of various species in either genus. They chiefly exist in *Palaemon*, having a longer rostral spine and a dorsal spine being present on the posterior margin of the fifth somite of the pleon.

It would be interesting, should we have the opportunity, to compare the larva of the enormous freshwater Prawn of Guatemala, a crustacean as large as a half-grown Lobster, with that of our European species.

Palinurus marinus.

In my last Report are given figures of the young of the genus *Palinurus*, an animal that has excited considerable attention amongst carcinologists in consequence of its near resemblance to the form of *Phyllosoma*, a circumstance that has induced many zoologists to believe that they are but the same animal in different stages of growth. Since the presentation of the second Report, in which I gave certain reasons for not too readily accepting this conclusion, Dr. Anton Dohrn has given much time to the subject, and traced the development of the ovum from the commencement to the period when the young animal quits the egg-case. He writes to me from Messina, February 1869:—"I only assure you that the thing is finished. The *Phyllosoma* are the larvæ of the *Loricata*. I have followed the development of *Scyllarus* and *Palinurus* eggs, and both have brought out *Phyllosoma*. What is there so anomalous in *Phyllosoma*? It is nothing but a depressed *Megalops*. . . . I have followed the development of the interior organization as well, and there is no difference of real value between *Phyllosoma* and *Scyllarus*, or *Palinurus*."

This, which gives the author such confidence, is nothing more than has been known for the last twenty years. The question is not as to the forms of the larva of *Palinurus*, *Scyllarus*, &c., but whether certain animals that are like them, but five hundred times as large, that we find mostly in exotic seas, are the same but a little older specimens. If they are, as Dr. Dohrn and other naturalists affirm, then they establish the remarkable fact that the larvæ of these Crustacea grow from the one-tenth of an inch in length to that of one or two inches in length, without any material variation of form, a feature that is not consistent with the life-history of the development of the animals of this class.

If we examine the progressive growth of other Crustaceans, we find that with every increase in growth there is a fresh moult, and every moult develops the animal a stage nearer the type of the adult animal. If the *Phyllosoma* be, as contended, the young of *Palinurus*, then an arrest in progressive development takes place, while that of growth continues.

An argument in favour of this being the case (that *Phyllosoma* may be the young of *Palinurus*) may be found in a species described by De Haan in Siebold's 'Fauna Japonica' under the name of *Ph. Guerinii*, in which an intermediate progressive step exists, inasmuch as the carapace is developed so far posteriorly as to cover the pereon.

I think, therefore, that although step by step we may arrive at the true knowledge, yet the large amount of negative evidence, which is capable at any day of being overthrown, must make us hesitate in accepting as a thing proved the statement that *Phyllosoma* and the closely resembling larva of *Palinurus* are one and the same creature.

The genus *Scyllarus* has now been so frequently captured on our coast, that we must consider it not as a mere straggler, but as an old inhabitant of the British seas.

Mr. Cornish writes:—"Some years since I suggested to Prof. Bell, with the first specimen that I took, that it was identical with the little lobster described by Borlase (Nat. Hist. p. 274) as 'that fine Shrimp (*Squilla lata*, Rondeletii) I found in Careg-Killas, in Mount's Bay;' but he thought that *Squilla lata* was the other *Scyllarus*, and not mine. I now believe that I was right and he was wrong. Looking at the rarity of the species in Mount's Bay, it is more probable that Borlase's specimen and mine should be the same species, than that they should be distinct."

Borlase took his on Careg-Killas, in Mount's Bay. This name is lost; but it means "slate," or "killas-rock," and it was (*vide* Borlase, Nat. Hist. p. 254) "a ledge where loose stones could be turned over," near Penzance (p. 206).

There are but two places in Mount's Bay which satisfy this description, and the one nearest to the Doctor's residence is Long Rock, where the latest specimen of *Scyllarus* was taken.

Besides which, Pennant (vol. iv. p. 17, No. 23, *Lobster*) speaks of *Squilla lata*, Rondeletii, as the size of the *Spiny Lobster*. Dr. Borlase speaks of his specimen as "that fine shrimp."

The specimen of which Mr. Cornish writes was captured alive, and, being in full spawn, was sent on to me, with the hope that, should it arrive alive, I might be able to hatch the ova, and so make out the hitherto undetermined form of the young *Scyllarus*. Unfortunately the animal was dead when it reached me that same evening. The ova were very abundant in quantity, each being about $\frac{1}{10}$ of an inch in diameter, with an orange-coloured vitellus. The embryo was in a very immature stage, so that little could be learned from it as to the form or character of the larva when it quits the ovum. My friend Dr. Andrew Dohrn, however, who has on the coast of Sicily been giving his attention to this subject amongst others, informs me that the larva of *Scyllarus* is identical with that of *Palinurus*, and consequently assumes the form of *Phyllosoma*.

Squilla.

Several specimens of this genus have been recorded from the coasts of Devon and Cornwall; but the scarcity of their appearance induces us to consider them rather as stragglers drifted from the Channel Islands than inhabitants of our southern shores. Two other genera of closely allied animals are occasionally taken in the same locality. These have been described by Prof. Milne-Edwards, and figured under the respective names of *Alima* and *Squillerichthys*; specimens of both these have been taken during the last summer, the former by Mr. Ray Lankester, and the latter by Mrs. Collings of Serk. The former of these animals has much in its appearance that is suggestive of an undeveloped condition; but it was difficult to define the parent stock; it might be a young *Squillerichthys*, or it might be a young *Squilla*, from either of which it differs in having but two flagella to the anterior appendage, and in the absence of the five pairs of pereiopoda; while in *Squilla* and *Squillerichthys* there are three flagella to the anterior antennae, and all the pereiopoda are present. The general form, however, of *Alima* is

nearer to *Squilla* than is *Squilla* to *Squilla*. This separation appears to receive a wider demarcation from the circumstance that Mrs. Collings took attached to her specimen several small ova; two of these, with the specimen, she kindly forwarded to me for inspection. These, however, after due consideration, I came to the conclusion were only accidentally entangled, or else deposited by some parasitic animal, since they were attached to a large flexible membrane differing essentially from those that cover the ova of Crustacea generally.

Fortunately, however, Dr. Power, while staying in the Mauritius, hatched and forwarded to me a considerable number of the young of different Crustacea; among these were those of a *Squilla*. This, although the young of an exotic species, bears so close a relation to the genus *Alima* of Milne-Edwards, that we can have no hesitation in accepting them as different stages in the growth of animals of the same genus.

So with *Squilla*, the features that distinguish it from *Squilla* being clearly expressed in the larva of *Squilla*, and repeated in the form of *Alima* in a condition that is a modification between it and *Squilla*, conduces to the conviction that, like *Alima*, *Squilla* is but a stage in the development of *Squilla*, a circumstance that enables us with much confidence to unite the three supposed genera as different stages in the progressive development of one and the same genus.

In the entrance to the channel, during the present spring, large quantities of the Crustacea named by Prof. Bell, in his 'History of the British Crustacea,' *Thysanopoda Couchii*, were taken in the stomachs of fish; of these a considerable number were sent to me by Mr. Loughrin, but they were not in a condition favourable for examination. The pendulous ovipouch, that affords such a peculiar feature to the animal, was generally of a bright orange-colour; but, generally speaking, the contents had been so acted upon by the digestive juices that little was determinable from them. This I think we may speak with certainty, that they are not of the genus *Thysanopoda*.

OSTRACODA.

The following Ostracoda, which have been examined for us by G. S. Brady, F.L.S., were dredged off the Eddystone in 40 fathoms of water:—

Pontocypris mytiloides, Norman.

— *trigonella*, G. O. Sars.

— *angusta*, Brady.

Bairdia inflata, Norman.

— *acanthigera*, Brady.

Cytherea pollucida, Baird.

— *tenera*, Brady.

— *hadia*, Brady.

— *convexa*, Baird.

— *finmarchica*, Sars.

— *villosa*, Sars.

— *emaciata*, Brady.

— *semipunctata*, Brady.

— *cuneiformis*, Brady.

— *antiquata*, Baird.

— *Jonesii*, Baird.

— *acerosa*, Brady.

Eucythere parva, Brady.

Loxococoncha impressa, Baird.

Loxococoncha guttata, Norman.

— *tamarindus*, Jones.

Xestoleberis aurantia, Baird.

Cytherura angulata, Brady.

— *cuneata*, Brady.

— *striata*, Sars.

— *similis*, Sars.

— *acuticostata*, Sars.

Cytheropteron punctatum, Brady.

— *nodosum*, Brady.

— *multiforum*, Norman.

— *subcircinatum*, Sars.

Bathocythere constricta, Sars.

— *turgida*, Sars.

Pseudocythere caudata, Sars.

Sclerochilus contortus, Norman.

Paradoxostoma ensiforme, Brady.

— *abbreviatum*, Sars.

Polycopse compressa, Brady.

ANNELIDS.

Dr. McIntosh, F.R.S.E., F.L.S., says a considerable collection of Annelids

from the neighbourhood of Plymouth was sent to me for examination by Mr. Spence Bate and Mr. Brooking Rowe; the former likewise courteously gave me the use of some careful drawings, from which sources the following list is drawn up. As not unfrequently happens with such animals, the specimens were in an indifferent state of preservation, especially those which had been placed in glycerine. Although somewhat softened, however, they were of great interest, and much care had evidently been bestowed on their collection. As a series entirely from the southern shores of England, they form an advantageous contrast with the collections of Mr. Gwyn Jeffreys, which come from the opposite extremity of the British Islands, viz. from the Zetlandic seas.

The majority of the species are well-known forms, and with regard to these it is only necessary to refer to the list. Amongst the rarer forms, *Lepidonotus clava*, Mont., seems to be plentiful, whereas on most of our shores it is not commonly met with. Its speckled and adherent scales, swollen and ringed cirri, and stout yellow bristles render it an easily recognized species. The *Nereis Marionii*, Aud. & Ed., has not hitherto been recorded as British, and appears to be chiefly a southern form, for I have not yet found it elsewhere than in the Channel Islands and in this collection from Plymouth. It is characterized by the great development of the superior lobe of the foot towards the posterior end of the body. *Onuphis sicula*, De Quatref., is also comparatively common. The range of this species extends from the Shetland Islands to the Mediterranean. It has jointed bristles, as in *Eunice*, and the examples were in tubes of gravel and sand. The very large size of some of the specimens of *Cirratulus cirratus* calls for notice. I have not seen larger. The occurrence of *Terebella melusa*, Sav., a gigantic form, is likewise interesting; and it is probable that *Terebella gigantea* of Montagu refers to this species. The hooks correspond with that figured by Dr. Malmgren*, from a specimen procured in the Red Sea near Suez, and have five (rarely six) distinctly separated teeth. The *Terebella* (*Polynnia*) *Danielsseni* of Malmgren is a new British form, distinguished by the three comparatively short branchiæ and the shape of the hooks, which have a large fang and two or three small teeth above it.

List of Species.

<i>Hermione hystrix</i> , Sav.	<i>Iambrinereis fragilis</i> , Müll.
<i>Lepidonotus squamatus</i> , Linn.	<i>Eunice</i> ———?
—— <i>clava</i> , Mont.	<i>Leodice norvegica</i> , L.
<i>Harmothoe imbricata</i> , Linn.	<i>Lysidice ninetta</i> , A. & Ed.
—— <i>longisetis</i> , Grube.	<i>Hyalinaster tubicola</i> , Müll.
<i>Polynnia asterina</i> (squamosa, <i>Delle Chiaje</i>).	<i>Onuphis sicula</i> , Quatref.
Attached to <i>Astoria aurantiaca</i> .	<i>Notocirrus scoticus</i> , Mr. I.
<i>Sigalion boia</i> , Johnst.	<i>Glycera capitata</i> , Erst.
<i>Nephtys</i> ———?, softened fragment.	—— <i>Gössi</i> , Malm.
<i>Notophyllum polynoides</i> , Erst.	<i>Arenicola caudata</i> , Johnst.
<i>Eulalia viridis</i> , Müll.	<i>Chatopterus norvegicus</i> , Sars. (Drawing.)
<i>Eteone pusilla</i> , Erst.	<i>Nereis vulgaris</i> , Johnst.
<i>Syllis armillaris</i> , Müll.	<i>Scolecoplepis cirrata</i> , Sars.
<i>Gattiola spectabilis</i> , Johnst.? (Drawing.)	<i>Cirratulus cirratus</i> , Müll.
<i>Nereis zonata</i> , Malmgren?	<i>Capitella capitata</i> , Fabr.
—— <i>pelagica</i> , L.	<i>Ammonchares Ottonis</i> , Grube.
—— <i>Marionii</i> , A. & Ed.	<i>Subellaria alveolata</i> , L.
—— <i>cultrifera</i> , Grube.	<i>Pectinaria belgica</i> , Pallas.
<i>Nereilepas fucata</i> , Sav.	<i>Amphictene auricoma</i> , Müll.
<i>Eunereis longissima</i> , Johnst.	<i>Amphictes Gunneri</i> , Sars.

* Nordiska Hafs-anqulator, tab. 25, f. 80.

Terebella medusa, Sav.

— *nebulosa*, Mont.

— *littoralis*, Dalyell, &c.

— *Danielsseni*, Mgrn.

Nicola zostericola, Erst.

Pista cristata, Müll.

Thelepus circinnatus, Fabr.

Leprea tetrica, Dalyell.

Sabella poncillius, L. (*pavonia*, Sav.).

Dasychone Dalyelli (Dal.), Kolliker.

Protula protensa, Lam. & Grube.

Serpula vermicularis, L.

Serpula reversa, Mont.

— *triqueter*, L.

Pontobdella muricata, L.

Borlasia olivacea, Johnst.

Lineus longissimus, Simmons.

Micrura fusca?

Onmatopsea. Several.

Sipunculus?

Thalassema Neptuni, Gartner.

FORAMINIFERA.

The Foraminifera, of which the following list was furnished me by Mr. David Robertson of Glasgow, were taken in about 40 fathoms seven miles south-east of the Eddystone, and some fourteen miles south-east of the Dudman, in about the same depth of water.

Cornuspira foliacea, Phil.

Biloculina depressa, d'Orb.

Spiroloculina limbata, d'Orb.

— *planulata*, Lamarck.

Triloculina oblonga, Mont.

Quinqueloculina seminulina, d'Orb.

— *subrotunda*, Mont.

Trochammina inflata, Mont.

Lituola canariensis, d'Orb.

Lagena lavis, Mont.

— *striata*, Mont.

— *semistriata*, Will.

— *globosa*, Mont.

— *melo*, d'Orb.

Dentalina communis, d'Orb.

Cristellaria rotulata, Lamk.

— *crepidula*, F. & M.

Polymorphina lactea, W. & J.

Polymorphina oblonga, Will.

— *compressa*, d'Orb.

— *myristiformis*, Will.

Orbulina universa, d'Orb.

Spirillina vivipara, Ehrenb.

— *margaritifera*, d'Orb.

Textularia sagittula, Lamk.

Bulimina pupoides, d'Orb.

— *ovata*, d'Orb.

Bolivina punctata, d'Orb.

Discorbina globularis, d'Orb.

Planorbulina mediterraniensis, d'Orb.

Truncatulina lobatula, Walker.

Rotalia Beccarii, L. & M.

Patellina corrugata, Will.

Nonionina asterizans, F. & W.

— *turgida*, Will.

Report on the practicability of establishing "A Close Time" for the protection of indigenous Animals. By a Committee, consisting of F. BUCKLAND, Rev. H. B. TRISTRAM, F.R.S., TEGETMEIER, and H. E. DRESSER (Reporter).

IN accordance with the resolution passed at the Meeting of the British Association at Norwich in August last, appointing Mr. Frank Buckland, Rev. H. B. Tristram, Mr. Tegetmeier, and Mr. H. E. Dresser as a Committee for the purpose of collecting evidence as to the practicability of establishing a close time for the protection of indigenous animals, this Committee met at the Zoological Society's rooms (which Dr. Sclater had kindly placed at their disposal) on the 13th of January last, the Rev. Dr. Tristram being in the chair; and on Professor A. Newton tendering in evidence the information published by the Yorkshire Association for the Protection of Sea-birds, respecting the utility of sea-birds, it was resolved, inasmuch as the said Association was working in the same direction as this Committee, that we should give every reasonable assistance in furthering the object for which the Association had been formed, viz. that of getting an Act of Parliament passed to protect the

sea-birds during the breeding-season, the reasons given being that sea-birds are useful in destroying grubs and worms, in acting as scavengers in the harbours, in warning vessels off the rocks during fogs by their cries, and in hovering over and pointing out to the fishermen the locality of the shoals of fish.

At the above meeting Mr. J. E. Harting, F.L.S. &c. was proposed and elected as a member of this Committee.

Since then the members of your Committee have to the best of their power cooperated with the Association for the Protection of Sea-birds, and that Association has fully acknowledged the assistance rendered. The Bill for the protection of Sea-fowl was entrusted to the care of C. Sykes, Esq., M.P., in the Commons, and His Grace the Duke of Northumberland in the Lords, where it met with a most favourable reception.

Before the Bill passed into Committee a meeting of naturalists was held at the Hanover Square Rooms in order to consider and discuss the various clauses. However, as the progress of the Bill has been so fully reported in the newspapers, it is needless to enter into details here, and it will be sufficient to say that at first it was proposed to make it illegal, not only to kill the birds during the breeding-season, but also to take their eggs; and the close time was proposed to extend from the 1st of May to the 1st of August. However, it was found that so much injury would be inflicted on the poorer classes living on the coast if they were prevented from taking the eggs or young of the sea-birds, as they are often dependent on these for subsistence, that the egg clause was struck out, and the young, when unable to fly, were exempted. It was also considered that it would be expedient to exempt the island of St. Kilda, the inhabitants of that island being so entirely dependent on sea-birds for their subsistence.

With these modifications, and the close time being extended one month, or from the 1st of April to the 1st of August, the Bill became law in June last, and one conviction has already taken place. The person convicted under this Act had dead sea-gulls in his possession, and was heavily fined. The Bill for the protection of sea-birds having now become law, it has to be considered how far it will be advisable to press for its extension to other birds and mammals. That it will be well to afford protection to most, if not all, of our birds, at least during the breeding-season, your Committee are fully convinced; but it yet remains to convince the farmer that he will derive benefit from so doing.

Our British agriculturist is in general no naturalist, and takes it for granted that every grain-eating bird must do him harm. He accordingly does his best to exterminate sparrows and other small birds, little thinking of the *benefit* they render him in *destroying insects*. Nor will the *game-preservee*, we fear, countenance so sweeping a measure until he is fully convinced that it is necessary to put some limit to the ravages made by his gamekeeper amongst our feathered friends.

On the continent, and particularly where zoology forms a branch of study in the schools of agriculture (as in Germany, Sweden, &c.), the utility of many of our birds, which with us are persecuted as vermin, is fully recognized, and instead of forming sparrow clubs, the agriculturists there take steps to protect the feathered tribes.

In the grain-growing countries of Russia near and in every village small boxes and sections of hollow branches may be seen fixed on to trees, barns,

* We may here state that an Act protecting the sea-birds, not only during the breeding-season, but during the whole year, has been for some time in force in the Isle of Man, and has had the effect of almost entirely stopping the destruction of sea-fowl on that island.

houses, &c., in order to induce sparrows and starlings to take up their abode there, and assist in freeing the crops from destructive insects. Sparrows, starlings, and particularly jackdaws swarm near most of these villages, and, according to what the peasants say, are of infinite use in freeing the crops from insects.

In Sweden, also, the starling is an especial favourite with the agriculturist, and the Principal of the Böda Forest School, Jägmästare Boman, makes every one of his pupils prepare and hang up a certain number of these nesting-boxes, or "holkar," before leaving the school.

The late Mr. Charles Waterton also recommended the introduction into England of this plan of providing nesting-boxes for starlings.

In speaking of the starling, we may refer to a letter from Universitäts Forstmeister Wiese, published in the 'Journal für Ornithologie,' 1866, p. 422, in which he urges the necessity of putting up nesting-boxes for starlings, and states that at Elisenhain in the Griefswald the oak-forests were suffering severely from the devastations of *Tortrix viridana*, when, to destroy this insect, the starlings were protected, and these birds soon succeeded in keeping down the numbers of this insect.

Some agriculturists of New Zealand are at the present moment endeavouring, at considerable expense, to introduce into those islands the rook, the jackdaw, and the starling, for the purpose of protecting their crops from the ravages of caterpillars and locusts.

The best mode of judging of the good or harm done by birds is most certainly that of *studying the nature of their food*; and as almost all our smallest birds, even those which are chiefly graminivorous, feed their *nestlings on insects*, it would surely benefit the farmer and gardener were they protected during the time when the insects are most destructive to the crops. Even the *Raptores* should, we think, be protected; and in proof of this we may refer to Professor Newton's paper on the "Zoological aspect of Game-Laws," read at the last Meeting of the British Association, and the Rev. Dr. Tristram's theory propounded at the Meeting in 1867, viz. that the birds of prey are the sanitary police of nature, and that if they had existed in their original strength they would have stamped out the grouse-disease, inasmuch as hawks in preference make sickly birds their quarry.

Regarding the food of our birds we may make the following short remarks:—

The common Buzzard (*Buteo vulgaris*), which was once, it is true, common in Great Britain, but is now rapidly approaching the fate of the Great Bustard, owing chiefly to the mistaken zeal of the gamekeepers, is a bird by no means injurious to game. Its food consists chiefly of frogs, mice, snails, &c., and but seldom or never of birds.

The Kestrel (*Falco tinnunculus*) feeds almost entirely on field-mice, but also eats beetles and grasshoppers.

The Merlin (*Falco cesalon*) feeds chiefly on mice and small birds.

The Sparrowhawk (*Accipiter nisus*) is perhaps the only true enemy of the game-preserver; though at the same time it is probable that if the good and evil it does were justly weighed, the balance would be in favour of the hawk, its favourite quarry being the Woodpigeon, which is now increasing to an extent injurious to agriculture.

As far as owls are concerned, Professor Newton clearly showed, at the last Meeting of the British Association, that these birds are of the greatest use to the agriculturist in destroying the small mammals which injure his crops. Prof. Newton refers to the researches of Dr. Altum, the results of

which were as follows:—In order to ascertain the nature of the food of the different owls, Dr. Altum collected pellets, or castings, at different seasons of the year, from different localities, which pellets he carefully examined.

Of the Barn-owl (*Strix flammea*) he examined 706 rejected pellets, which contained remains of the following, viz.:—

4	<i>Plecotus auritus.</i>	1	<i>Arvicola campestris.</i>
11	<i>Vesperugo pipistrellus.</i>	76	<i>Crossopus fodiens.</i>
1	<i>Vesperugo serotinus.</i>	349	<i>Crocidura araneus (and leucodon).</i>
3	<i>Mus decumanus.</i>	1164	<i>Sorex vulgaris.</i>
237	— <i>musculus, sylvaticus, and minutus.</i>	1	— <i>pygmaeus.</i>
34	<i>Hypudaeus glareolus.</i>	1	<i>Talpa europaea.</i>
23	— <i>amphibius.</i>	19	<i>Passer domesticus.</i>
588	<i>Arvicola arvalis.</i>	1	<i>Fringilla chloris.</i>
47	— <i>agrestis.</i>	2	<i>Cypselus apus.</i>

Of the Wood-owl (*Strix aluco*) he examined 210 pellets, the contents of which he classifies as follows—

1	<i>Mustela erminea.</i>	48	<i>Talpa europaea.</i>
6	<i>Mus decumanus.</i>	1	<i>Certhia familiaris.</i>
42	— <i>musculus, sylvaticus, minutus.</i>	1	<i>Emberiza citrinella.</i>
19	<i>Hypudaeus glareolus.</i>	1	<i>Motacilla alba.</i>
11	— <i>amphibius.</i>	15	Small birds (sp.?).
254	<i>Arvicola arvalis.</i>	15	<i>Carabus granulatus.</i>
12	— <i>agrestis.</i>	4	<i>Harpalus</i> — ?
1	<i>Sciurus vulgaris.</i>	9	<i>Ditiscus marginalis.</i>
5	<i>Crossopus fodiens.</i>	14	<i>Scarabeus stercorarius.</i>
3	<i>Crocidura araneus.</i>	1	— <i>sylvaticus.</i>
20	<i>Sorex vulgaris.</i>	1	<i>Elater</i> — ?
5	— <i>pygmaeus.</i>	1	<i>Silpha rugosa.</i>

and large quantities of *Melolontha vulgaris*, some of the pellets consisting entirely of the remains of these insects.

Of the Short-eared Owl (*Strix brachyotus*) he examined a few pellets, which he found to contain only remains of *Hypudaeus amphibius*; but as these were only obtained from one locality where this mouse is especially abundant, Dr. Altum reserves his remarks on the food of this owl until he can make further investigations.

Of the Long-eared Owl (*Strix otus*) he examined many pellets, which contained remains as follows:—

14	<i>Mus sylvaticus.</i>	65	<i>Arvicola agrestis.</i>
1	<i>Hypudaeus amphibius.</i>	2	<i>Sorex vulgaris.</i>
12	— <i>glareolus.</i>	3	Birds, sp.?
193	<i>Arvicola arvalis.</i>		

The above proves most clearly that our owls should be protected, as in destroying mice &c. they are benefitting the agriculturist. Not only, however, do the owls, as is above shown, feed chiefly on mice, but the Wood-owl (*Strix aluco*) is often insectivorous; and Mr. Leopold Martin of Berlin (Journal für Ornithologie, 1854, p. 93) states that he found in the stomach of one of these birds the remains of no less than 75 *Sphinx pinastri*.

Many of our smaller birds are entirely insectivorous, and are undoubtedly useful at all seasons of the year; and of these we may in particular refer to the Woodpeckers and Titmice, the latter of which feed largely on the eggs of *Bombyx pini*, which is so destructive to the pine forests. Every female of this moth will lay from 600 to 700 eggs, and were it not that they are kept down in number by the tits they would increase enormously. Count C. Wodziecki, in a small work on the influence of birds in destroying inju-

rious insects, published at Lemberg in 1851, calculates that a single tit will devour 1000 insects' eggs in a single day, and besides, the tits feed their young chiefly on insects' eggs and caterpillars. Count Wodzicki mentions in particular *Sitta europæa*, *Certhia familiaris*, and the *Regulidæ*, as being useful in destroying *Bombyx pini*. He also mentions that the Woodpeckers are of great utility in destroying the following insects, viz. *Noctua pinastri*, *Geometra pinivaria*, *Sphinx pinastri*, *Tenthredo pini*, *T. septentrionalis*, *Bostriehus typographus*, and *B. chalcographus*. M. C. von Heyden also remarks (Journal für Ornithologie, 1859, pp. 316, 317) that in the winter *Sitta europæa* and *Parus major* feed on the larvæ of *Cecidomyia fagi*, the Beech-gall insect, and states as follows:—"The well-known conical gall of this insect is often found in large numbers on the upper side of the beech-leaves. In the autumn it becomes hard like wood, and falls off the leaf. These birds then search carefully on the ground under the trees for the galls, and after pecking a hole (generally in the side of the point of the gall), pick out and devour the insect. The hole is generally so small that the insect cannot be extracted with the beak, and the bird must use its tongue for that purpose. It is curious that the bird should bore a hole at the hard point of the gall when the base is merely closed by the thin paper-like web of the insect."

Professor Buckman has also recently observed that the Blue-tit (*Parus cœruleus*) destroys the flies which make the oak-galls, which in many parts of the country threaten to ruin the young oak-plantations.

Many of our seed-eating birds are useful, not only because they feed on the seeds of injurious weeds, but also on destructive insects; and our common Yellowhammer (*Emberiza citrinella*) feeds with avidity on the caterpillar of the white Butterfly (*Pieris rapæ*).

Mr. Mewes, the well-known Swedish naturalist, states (Ötversigt af Kongl. Vetenskaps Akademiens Förhandlingar, 1868, p. 256) that at Borgholm in Sweden he found the oak-woods near the castle almost stripped of their leaves by *Tortrix viridana*, and that numbers of birds were feeding on the larvæ of this insect, amongst which he names the common Crossbill (*Loxia curvirostra*), which, though in general a seed-eater, was in that instance doing good service in eating insects. He states that flocks of these birds were busily employed in destroying this insect.

The much-persecuted Sparrow (*Passer domesticus*) is also a good friend to the agriculturist, and amply repays him for the little corn he may take by destroying many injurious insects, and in eating the seeds of many rank weeds.

During the winter the Tree-sparrow (*Passer montanus*) feeds chiefly on the seeds of *Urtica divica*, *Chenopodium album*, and *Polygonum aviculare*, all of which are injurious weeds.

It is true that the House-sparrow is a grain-eating bird, but its nestlings are fed chiefly on insects. Mr. Berthold Wicke, of Göttingen (Henneberg's Journal für Landwirtschaft, 16 Jahrgang, 3 Heft) examined the contents of the stomachs of 118 sparrows procured between the 21st of April and 24th of June, and gives the following results of his investigations:—Of these birds, 45 were adults and 73 young, ranging from the small naked nestling to the full-fledged bird. In the stomachs of three of the adult birds he found only grain, in one nothing but the remains of a few beetles; one had the stomach and crop so full of grain that he counted 50 grains; one stomach contained the seed of weeds, pieces of peas and seeds of *Stellaria media*, and the rest contained corn with the remains of beetles; and in one was the entire skin of a *Melolontha vulgaris*,

Whereas, however, the stomachs of the adult birds contained chiefly grain and but a small proportion of insect-remains, it proved to be entirely the reverse as regards the young birds. Out of the 73 he examined, the stomachs of 46 contained insects, larvæ, caterpillars, &c., and only 9 contained vegetable matter alone. Of the remaining stomachs 10 contained the remains of insects mixed with a few seeds, 7 contained chiefly seeds with a small proportion of insect-remains, and 1 contained eggshells and small stones without trace of anything else.

Our American cousins have recognized the utility of the sparrow, and have introduced it into New York, where it is now found comparatively numerous, and has been most useful in keeping the trees free from caterpillars, which before its introduction threatened seriously to injure them.

Our thrushes and blackbirds are also most useful to the gardener from the quantities of slugs and snails they destroy, and our rook is universally acknowledged to be a most useful bird.

Much information as to the nature of the food of birds is, however, yet needed in order to judge correctly of the amount of good or harm they do; and it would be well if the question were fully ventilated in the newspapers, and naturalists resident in different parts of the country encouraged to make investigations as to the nature of the food of the different species of birds, and compare the results of such investigations.

Your Committee felt, however, sure that the good done by birds will be found largely to predominate over the harm, and that it will prove expedient to afford them protection during the breeding-season.

It is, however, a measure that will require considerable time to carry through, and we would suggest that the best mode of affording the necessary protection to birds would be to prohibit the carrying of a gun during the breeding-season, as is now done in several parts of the continent, as, for instance, in Switzerland, some parts of France, &c. In the United States of North America, where freedom of action exists more perhaps than anywhere else, the close-time system is to a large extent carried out, and has proved most beneficial, though, as may be supposed, it is most difficult to enforce in a thinly populated country.

Much information is, however, yet needed as to the practical working of the close-time system in those countries where it has been in force, and your Committee hope ere long to be able to procure reliable particulars on this point.

Generally it is said to work excellently, and, far from interfering with the game-preservers, it has been found to act in harmony with their views. Were it enforced here in England it would have the good effect of stopping the damage done by idle men and boys, who on Sundays are in the habit of going out in the neighbourhood of the towns to shoot small birds.

Experimental Researches on the Mechanical Properties of Steel.

By W. FAIRBAIRN, LL.D., F.R.S., &c.

IN my last Report I had the honour of submitting to the Association an experimental inquiry into the Mechanical Properties of Steel, obtained from the different sources of manufacture in the United Kingdom. On that occasion several important experiments were recorded from specimens obtained

from the best makers ; and bars were received from others, the experiments on which were at that time incomplete. Since then I have had an opportunity of visiting the important works at Barrow-in-Furness, and from there I have received bars and plates of different qualities for the purpose of experiment, and such as would admit of comparison with those recorded in my last Report. I have also received specimens from Mr. Heaton for experiment, illustrative of the new process of conversion from crude pig iron (of different grades) to that of steel, as exhibited in the results contained in this Report.

In every experimental research connected with metals, it is necessary to ascertain, as nearly as possible, the properties of the ores, the quality of the material, and the processes by which they are produced. Generally this information is difficult to obtain, as in every new process of manufacture there is a natural inclination (where the parties are commercially interested) to keep it as long as possible to themselves, and hence the reluctance to furnish particulars. Of this, however, I can make no complaint, as Mr. Bessemer, the Barrow Company, and Mr. Heaton have unreservedly not only opened their works for inspection, but they have furnished every particular required (including chemical analysis) relative to the properties of the ores, and the processes by which they are reduced.

From this it will be seen that in some of the experiments I have had the privilege of recording the chemical as well as the mechanical properties of the specimens which have been forwarded for the purpose of experiment, and of ascertaining their respective and comparative values.

As regards the works at Barrow, I have, through the kindness of Mr. Ramsden and Mr. Smith the manager, received every facility for investigation, and they have kindly sent me the analyses of all the ores in use for the purpose of manufacturing both iron and steel. In these Works, it will be noticed that the manufacture is exclusively confined to the hæmatite ores, and that by the Bessemer process.

It is curious to trace the progressive development of the manufacture of steel from the earliest period down to the present time, and to ascertain how nearly the more premature and early stages of manufacture approaches to those of Bessemer and others in our own days. To show how closely they approximate in principle (the exception being in the vessels used and the power employed), I venture to quote from my own Report to the Barrow Company, in which the coincidence between the ancient and modern processes is exemplified.

In treating of the value of the hæmatite formation, I have stated that "we have no reliable accounts of the time when the hæmatite ores were first used for the purpose of manufacture. They must have existed contemporary with those in Sussex and the Forest of Dean ; for the numerous cinder-heaps in those counties and at Furness bear evidence of the smelting-process having been carried on from an early period, until the forests became exhausted during the reign of Elizabeth and her successors. The process by which the ores were reduced in those days was extremely rude and simple, and was probably no better than what had been practised from time immemorial at the ancient bloomeries, to which were attached artificial blasts, first practised in this country after the Roman conquest. What was the nature of the apparatus for producing this blast we are unable to ascertain ; but it is likely that two or more pairs of bellows may have been used, or the method, still practised by the natives of Madagascar, might have been adopted of fitting pistons loosely into the hollow trunks of trees. In whatever form the hæmatite ores were reduced, it is clear that the smelting-furnace was not in operation in

those days; and assuming that the bloomery was the only process in use, the result would be a species of refined iron or steel, which, deprived of the greater part of its carbon, would become malleable under the hammer.

"It is interesting to observe how nearly our improved modern process of making steel approaches to that of those rude and early times. The Bessemer system is neither more nor less than the old process of the bloomery and the Catalan furnace, the former being adapted to smelt the ore, and the latter to decarbonize and refine it into the malleable state of iron or steel.

"That such was the state of the early manufacture of hæmatite iron can hardly be questioned, as the country around Ulverston was covered with forests; and the name given to Furness Abbey shows that its site was in the vicinity of furnaces, employed exclusively for the reduction of the ores with which the surrounding country abounds. The remains of these ancient furnaces have to some extent been carried down to our own times, and Messrs. Harrison and Co. still manufacture a fine quality of charcoal iron, the wood being obtained from the adjoining forests. The new works at Barrow have, however, entirely changed the nature of this process; and the system of manufacturing direct from the ore has become a question of such importance, as to induce an investigation of its value, and the improvements it is likely to effect both in the manufacture of iron and steel. For this object the following experiments have been instituted, in order to show the peculiar properties of this manufacture, and the extent to which it is applicable for the general purposes of trade and constructive art.

"The proprietors of the Barrow Works have confined themselves to certain descriptions of manufacture, on the Bessemer principle, these being chiefly steel rails, tyres, plates, and girders, manufactured at a comparatively low price. From the nature of the ore and fuel (the latter of which is chiefly brought by rail from the coal-fields of Durham and Northumberland) a description of highly refined homogeneous iron and steel is produced; and as this manufacture is intended for purposes where tenacity and flexibility are required, it would not be just to compare it with other descriptions of manufacture, where the object to be attained is hardness, such, for instance, as that employed for carriage-springs and tools. The description of steel or iron required for rails, beams, girders, &c. is of a different character; tenacity combined with flexibility is what is wanted, to which may be added powers to resist impact. The same may be said of wheel-tyres and other constructions, where the strains are severe, and where the material is sufficiently ductile to prevent accidents from vibration, or those shocks and blows to which it may be subjected. Keeping these objects in view, the Barrow Company's Works have, to a great extent, been limited to this description of manufacture; and, judging from the ductility of the material as exhibited in the experiments, there is little chance of accidents from brittleness when subjected to severe transverse strains, or to the force of impact.

"In calculating the value of the hæmatite steel, we have been guided by the same formulæ as adopted for comparison with similar productions from other works. Very few of them, however, will admit of comparison, as no two of them appear to be alike. The hæmatite steel is manufactured, at the Barrow Works, for totally different purposes from those of other makers, and having the command of a variety of ores for selection (as may be seen from the analysis of the ores given in the Table) the desired quality of steel can be obtained at pleasure. We have therefore submitted the different specimens to the same tests as those received from other makers, not only for the purpose of ascertaining wherein their powers of resistance differ, but also

wherein consists their superiority as regards deflection, elongation, and compression, from all of which may be inferred their nature and properties, and the uses to which they may be applied. It is for this purpose we have applied the same formulae of reduction to each particular class of experiments as in the former cases, and the results have been embodied in the summaries. If, for example, it were required to know the modulus of elasticity, the work of deflection, or the unit of working strength, these will be found in their respective columns, carefully deduced from the experiments as given in the Tables. The same principle for ascertaining the amount of work done to produce rupture from tension has been followed, and the force required to produce compression with a given load has also been calculated with the same degree of care and attention to facts.

"As the Bessemer principle of manufacturing direct from the ore is calculated to produce great improvements and important changes in the production of refined iron and steel, and as the homogeneous properties of the material thus produced are of the highest importance as regards security, &c., it is essential to construction that we should be familiar with the mechanical properties of the material in every form and condition to which it may be applied.

"For this purpose I have given all the various forms of strain, excepting only that of torsion, which is of less moment, as the strains already described involve considerations which apply with some extent to that of torsion, and from which may be inferred the fitness of the material for the construction of shafts and other similar articles to which a twisting strain applies.

"The great advantage to be derived from the Barrow manufacture of steel is its ductility combined with a tensile breaking strain of from 32 to 40 tons per square inch. With these qualities I am informed that the proprietors are able to meet all the requirements of a demand to the extent of 1000 to 1200 tons of steel per week, which, added to a weekly produce of 4500 tons of pig-iron, will enable us to form some idea of the extent of a manufacture destined in all probability to become one of the most important and one of the largest in Great Britain"*.

From the above statement it may be inferred that the description of manufacture practised at Barrow is carried on upon a large scale, and the products have reference to certain properties almost exclusively adapted to the formation of wheel-tyres, rails, and plates. To the attainment of these objects the greatest care and attention is devoted by the Company, as may be seen by comparing the reduction of the experiments in the summary of results.

In this extended inquiry I have endeavoured to deduce true and correct results from the specimens with which I have been favoured from the Barrow Steel Company. In the same manner I have now to direct attention to the products of an entirely new system of manufacture introduced by Mr. Heaton of the Langley Mills, near Nottingham. The experiments on this peculiar manufacture require a separate introductory notice, as the process of conversion is totally different to that of Bessemer, the Puddling-furnace, or that of the old system of the Charcoal-beds.

For the finer description of steel the old process of conversion is still practised at Sheffield, from a fortnight to three weeks being required for the conversion of wrought iron into steel; and, with the exception of Mr. Siemens's Reverberatory Gas-furnace, there no improvements had been made on it until

* In round numbers, it is stated that the produce of the Barrow Mines is 600,000 tons of ore per annum; of the Barrow Blast-furnaces 230,000 tons of pig-iron; and of the Rolling Mills 60,000 tons of steel rails, tyres, plates, &c.

Mr. Bessemer first announced his invention by means of which melted pig-iron was at once converted into steel.

This new process of forcing atmospheric air through the metal in a molten state took metallurgists by surprise; and when it was taken into consideration that the conversion was effected in twenty minutes and at one heat, the question became one of absorbing interest to the whole of the commercial population.

By the old process the metal was first deprived of its carbon and reduced to the malleable state, when it was rolled into bars and retained (as above described) from fourteen to twenty-one days in charcoal-beds until it had absorbed by cementation the necessary quantity of carbon. The new process of Mr. Heaton, unlike that either of Mr. Bessemer or of cementation, simply deals with the pig-iron, and, according to his own statement, eliminates the superfluous carbon, so that steel is in the first place produced and thence wrought iron by a still further elimination of the carbon. This is totally different to the puddling or the Bessemer process, which in the former was tedious and expensive, whilst in the latter the pig-iron was rendered malleable without any additional fuel and ready for the hammer or the rolls in a very short period of time.

It is unnecessary to notice in detail the subsequent mechanical processes of reheating, rolling, hammering, &c., which are common to all the systems of conversion; it is, however, important to mention that an admixture of *spiegeleisen*, a description of cast iron containing an excess of carbon, is made into the molten mass, without which the conversion is not easily effected by the Bessemer process.

It is asserted by some writers on this subject, "that, whatever are the merits of the Bessemer process, the conversion cannot be effected without a destructive action upon the converters, and a rapid wear and tear of the tuyeres, that there is waste in filling the moulds, and that the heavy royalties attached to the patents &c. are serious drawbacks to the extension of the process." Mr. Hewitt, a writer on this subject, comes to the conclusion "that good steel can only be made from good material, no matter what process is employed;" and he further states "that the Bessemer process will not, as Mr. Bessemer originally supposed, supersede the puddling-process, which appears to be as yet the only method applicable to the conversion of by far the greater portion of pig-iron made into wrought iron, because by far the larger portion of pig-iron made is of a quality not good enough for the Bessemer process, which absolutely exacts the absence of sulphur and phosphorus."

There may be some truth in this statement, as it was found necessary, in the selection of the hæmatite ores at Barrow, to make use of the best quality, and only seven or eight out of twenty sorts were found suitable for the purpose. It is, however, evident from the rapid extension of the process and the estimation in which it is held by manufacturers and the general public, that whatever objections the process is subject to (on purely economical grounds) Mr. Bessemer has succeeded in carrying out the pneumatic principle of conversion to the highest degree of excellence at present attainable by that process.

In so important a branch of metallurgy it would be remarkable if Mr. Bessemer had hit upon the only feasible means of converting iron into steel. Other minds have been inspired by Mr. Bessemer's success in the same direction; and the admixture of metals to effect a transmutation has been assumed in many forms and proportions so as to increase our knowledge and lessen the cost of production. Amongst those is the new process of Mr. Heaton, a de-

scription of which we venture to transcribe from a pamphlet published by the proprietors of the Heaton process.

"The furnace (which is a common cupola) is charged with pig-iron and coke, and fired in the usual way, and the iron when melted is drawn off into a ladle, from which it is transferred to the converter.

"The converter is a wrought-iron pot lined with fire-brick. In the bottom is introduced a charge of crude nitrate of soda, usually in the proportion of 2 cwt. per ton of converted steel, usually but not invariably diluted with about 25 lb. of siliceous sand. This charge is protected or covered over with a close-fitting perforated iron plate weighing about 100 lb., the diameter of the plate being about 2 feet. The converter, with its contents, is then securely attached, by moveable iron clamps, to the open mouth of a sheet-iron chimney, also lined for 6 feet with fire-brick, and the melted iron taken in a crane ladle from the cupola is poured in. The subsequent part of the process is thus described by Professor Miller.

"In about two minutes a reaction commenced. At first a moderate quantity of brown nitrous fumes escaped; these were followed by copious blackish, then grey, then whitish fumes, produced by the escape of steam, carrying with it in suspension a portion of the flux. After the lapse of five or six minutes, a violent deflagration occurred, attended with a loud roaring noise and a burst of brilliant yellow flame from the top of the chimney. This lasted for about a minute and a half, and then subsided as rapidly as it commenced. When all had become tranquil, the converter was detached from the chimney, and its contents were emptied on to the iron pavement of the foundry.

"The crude steel was in a pasty state and the slag fluid; the cast-iron perforated plate, which was placed as a cover to the converter, had become melted up and incorporated with the charge of molten metal. The slag had a glassy or blebby appearance, and a dark or green colour in mass.' Professor Miller proceeds to detail the subsequent parts of the process, and the results of his analysis of some of the products.

"A mass of crude steel from the converter was then subjected to the hammer.

"About $4\frac{1}{2}$ cwt. of the crude steel was transferred to an empty but hot reverberatory furnace, where in about an hour's time it was converted into four blooms, each of which was hammered, rolled into square bars, cut up, passed through a heating-furnace, and rolled into rods varying in thickness from 1 inch to five-eighths of an inch.

"Three or four cwt. of the crude steel from the converter was transferred to a reheating furnace, then hammered into flat cakes, which, when cold, were broken up and sorted by hand for the steel melter.

"Two fireclay pots, charged with a little clean sand, were heated, and into each 42 lb. of the cake steel was charged; in about six hours the melted metal was cast into an ingot.

"Two other similar pots were charged with 35 lb. of the same cake steel, 7 lb. of scrap steel, and 1 ounce of oxide of manganese. These also were poured into ingots.

"The steel was subsequently tilted, but was softer than was anticipated.

"These results are on the whole to be considered rather as experimental than as average working samples.

"I have therefore made an examination of the following samples only:—

No. 4. Crude Cupola Pig.

No. 8. Rolled Steely Iron.

No. 7. Hammered Crude Steel.

No. 5. Slag from the converter.

“I shall first give the results of my analysis of the three samples of metal :—

	Cupola Pig (4).	Crude Steel (7).	Steel Iron (8).
Carbon	2·830	1·800	0·993
Silicon, with a little Titanium	2·950	0·266	0·149
Sulphur	0·113	0·018	traces.
Phosphorus	1·455	0·298	0·292
Arsenic	0·041	0·039	0·024
Manganese	0·318	0·090	0·088
Calcium	..	0·319	0·310
Sodium	..	0·144	traces.
Iron (by difference)	92·293	97·026	98·144
	100·000	100·000	100·000

“It will be obvious from a comparison of these results that the reaction with the nitrate of soda has removed a large proportion of the carbon, silicon, and phosphorus, as well as most of the sulphur. The quantity of phosphorus (0·298 per cent.) retained by the sample of crude steel from the converter which I analyzed is obviously not such as to injure the quality*.

“The bar iron was in our presence subjected to many severe tests. It was bent and hammered sharply round without cracking. It was forged and subjected to a similar trial, both at dull red and a cherry-red heat without cracking; it also welded satisfactorily.

“The removal of the silicon is also a marked result of the action of the nitrate.

“It is obvious that the practical point to be attended to is to procure results which *shall be uniform* so as to give steel of uniform quality when pig of similar composition is subjected to the process. The experiments of Mr. Kirkaldy on the tensile strength of various specimens afford strong evidence that such uniformity is attainable.

“I have not thought it necessary to make a *complete* analysis of the slag, but have determined the quantity of sand, silica, phosphoric and sulphuric acid, as well as the amount of iron which it contains. It was less soluble in water than I had been led to expect, and it has not deliquesced though left in a paper parcel.

“I found that out of 100 parts of the finely powdered slag, 11·9 were soluble in water. The following was the result of my analysis :—

Sand	47·3
Silica, in combination	6·1
Phosphoric acid	6·8
Sulphuric acid	1·1
Iron (a good deal of it as metal)	12·6
Soda and lime †	26·1
	100·0

* It is important to point out that, as no analysis of the finished steel tested by Mr. Kirkaldy is given, it is not improbable that this small percentage of phosphorus might have been still further reduced before it arrived at its final state of manufacture.

† The use of lime was exceptional. Its use is now discontinued; but its use on that occasion no doubt accounted for the slag being less deliquescent and soluble than it is usually found to be.

“ This result shows that a large proportion of phosphorus is extracted by the oxidizing influence of the nitrate, and that a certain amount of the iron is mechanically diffused through the slag.

“ The proportion of slag to the yield of crude steel iron was not ascertained by direct experiment; but, calculating from the materials employed, its maximum amount could not have exceeded 23 per cent. of the weight of the charge of molten metal. Consequently the 12·6 per cent. of iron in the slag would not be more than 3 per cent. of the iron operated on.

“ In conclusion, I have no hesitation in stating that Heaton's process is based upon correct chemical principles; the mode of attaining the result is both simple and rapid. The nitric acid of the nitrate in this operation imparts oxygen to the impurities always present in cast iron, converting them into compounds which combine with the sodium; and these are removed with the sodium in the slag. This action of the sodium is one of the peculiar features of the process, and gives it an advantage over the oxidizing methods in common use.

“ The slag produced is already utilized at the works, and forms the subject of a new and valuable patent. There is every reason to believe that the products of combustion may, by the means of a mechanical arrangement, devised by Mr. Heaton, be further utilized and afford a large set-off on the original cost of the nitrate. It is also a great question whether the phosphorus may not be most profitably reduced from the slag for commercial purposes.”

In addition to Mr. Miller's statement, Mr. Robert Mallet reported on the subject and expressed himself highly satisfied with the results, both as regards the chemical and physical properties of the metal; and having been present at the experiments made on Mr. Kirkaldy's testing machine, he states the results as under:—

	Rupturing strain, in tons, per square inch of section.	Extension at rupture, per cent. of original length.
Heaton's steel iron	22·72	21·65 per inch.
Heaton's cast steel	41·73	7·20 ,,

The results recorded in the above Table for cast steel are somewhat below the results obtained in my own experiments, being in the ratio (for the breaking strain) as 41·73 : 44·94, or as ·936 : 1.

The whole of these experiments appears to be correct; and assuming the statement of cost to be equally satisfactory, we arrive at the conclusion that “ taking steel from the furnace in ingots, or made into steel rails, or bar iron, or in any other form of ordinary manufacture, the net cost of production, after adding 10 per cent. for management, including all cost of labour, fuel, and material, and making all allowances for wear and tear and the like, is *several pounds sterling per ton* under the present market prices of similar descriptions of the metal.” And this will cease to be a matter of surprise when it is taken into consideration that, to repeat the words of Mr. Mallet, “ steel can be produced from coarse, low-priced brands of crude pig-irons, rich in phosphorus and sulphur.” “ Thus,” continues Mr. Mallet, “ wrought iron and cast steel of very high quality have been produced from Cleveland and Northamptonshire pig-irons, rich in phosphorus and sulphur; and every iron-master knows that first-class wrought iron has not previously been produced from pig-iron of either of these districts, nor marketable steel at all.”

With these observations I have now to refer to the drawings of the furnaces and apparatus which I have attached in illustration as an Appendix. In conclusion I may state that, looking at this new process and its further development as a step in advance of what has already been done by Bessemer and others, we may reasonably look forward to a new and important epoch in the history of metallurgic science.

Before entering upon the experiments, it will be necessary to repeat the formulæ of reduction as given in my previous Report of 1867. This appears to be the more requisite, as it may be inconvenient to refer to the Transactions of 1867, where it was originally introduced.

FORMULÆ OF REDUCTION.

For the reduction of the Experiments on Transverse Strain.—When a bar is supported at the extremities and loaded in the middle,

$$E = \frac{wl^3}{4\delta Kd^3}, \quad \dots \dots \dots (1)$$

where l is the distance between the supports, K the area of the section of the bar, d its depth, w the weight laid on added to $\frac{5}{8}$ of the weight of the bar, δ the corresponding deflection, and E the modulus of elasticity.

$$E = \frac{wl^3}{4\delta d^4}, \quad \dots \dots \dots (2)$$

when the section of the bar is a square.

These formulæ show that the deflection, taken within the elastic limit, for unity of pressure is a constant, that is, $\frac{\delta}{w} = D$, a constant.

Let $\frac{\delta_1}{w_1}, \frac{\delta_2}{w_2}, \dots, \frac{\delta_n}{w_n}$ be a series of values of D , determined by experiment in a given bar, then

$$D = \frac{1}{n} \left(\frac{\delta_1}{w_1} + \frac{\delta_2}{w_2} + \dots + \frac{\delta_n}{w_n} \right), \quad \dots \dots \dots (3)$$

which gives the mean value of this constant for a given bar.

Now, for the same material and length,

$$\frac{\delta}{w}, \text{ or } D \propto \frac{1}{Kd^3}; \quad \dots \dots \dots (4)$$

and when the section of the bar is a square,

$$\frac{\delta}{w}, \text{ or } D \propto \frac{1}{d^4}. \quad \dots \dots \dots (5)$$

If D_1 be put for the value of D when $d=1$, then

$$D_1 = Dd^4 = \frac{1}{n} \left(\frac{\delta_1}{w_1} + \frac{\delta_2}{w_2} + \dots + \frac{\delta_n}{w_n} \right) d^4, \quad \dots \dots \dots (6)$$

which expresses the mean value of the deflection for unity of pressure and section. This mean value, therefore, may be taken as the *measure of the flexibility* of the bar, or as the *modulus of flexure*, since it measures the amount of deflection produced by a unit of pressure for a unit of section.

Substituting this value in equation (2), we get

$$E = \frac{l^3}{4D_1}, \quad \dots \dots \dots (7)$$

which gives the mean value of the modulus of elasticity, where D_1 is determined from equation (6).

The work (U) of deflection is expressed by the formula

$$U = \frac{1}{2} \times w \times \frac{\delta}{12} = \frac{w\delta}{24}, \quad \dots \dots \dots (8)$$

where δ is the deflection in inches corresponding to the pressure (w) in lbs. If w and δ be taken at, or near the elastic limit, then this formula gives the work, or resistance analogous to impact, which the bar may undergo, without suffering any injury in its material. This formula, reduced to unity of section, becomes

$$u = \frac{w\delta}{24K}, \quad \dots \dots \dots (9)$$

If C be a constant, determined by experiment for the weight (W) straining the bar up to the limit of elasticity, so that the bar may be able to sustain the load without injury, then

$$\frac{Wl}{4} = CKd, \quad \dots \dots \dots (10)$$

where $C = \frac{1}{8} S$, or $\frac{1}{8}$ of the corresponding resistance of the material per square inch at the upper and lower edges of the section,

$$\therefore C = \frac{Wl}{4Kd}, \quad \dots \dots \dots (11)$$

When the section of the bar is a square,

$$C = \frac{Wl}{4d^3}, \quad \dots \dots \dots (12)$$

which gives the value of C , the modulus of strength, or the unit of working strength, W being the load, determined by experiment, which strains the bar up to the elastic limit. This value of C gives the comparative permanent or working strength of the bar.

Up to the elastic limit the deflections are proportional to their corresponding strains, but beyond this point the deflections increase in a much higher ratio. Hence the deflection corresponding to the elastic limit is the greatest deflection which is found to follow the law just explained.

For the reduction of the Experiments on Tension and Compression.—The work u expended in the elongation of a uniform bar, 1 foot in length and 1 inch in section, is expressed by

$$U = \frac{1}{2} \cdot \frac{P}{K} \cdot \frac{l}{L} = \frac{1}{2} P_1 l_1, \quad \dots \dots \dots (13)$$

where $P_1 = \frac{P}{K}$ = strain in lbs. reduced to unity of section, and $l_1 = \frac{l}{L}$ = the corresponding elongation reduced to unity of length.

The value of u , determined for the different bars subjected to experiment, gives a comparative measure of their powers of resistance to a strain analogous to that of impact.

By taking P_1 to represent the crushing pressure per unity of section, and l_1 the corresponding compression per unit of length, the foregoing formula will express the work expended in crushing the bar.

Having given the formulæ for calculating the resisting powers of the steel bars to a transverse, tensile, and compressive strain, and the amount of work expended in producing fracture, we now proceed to the experiments, as follows.

Analysis of Iron Ores used at the Barrow Hæmatite Iron and Steel Company's Works, Barrow-in-Furness, Lancashire.

No.	Name.	Water.	Solution.								Insoluble Residue.							
			Sesqui-oxide of iron.	Iron.	Phos- phoric acid.	Phos- phorus.	Sul- phuric acid.	Car- bonic acid.	Silica.	Alu- mina.	Prot- oxide of man- ganese.	Lime.	Mag- nesia.	Total.	Silica.	Alu- mina.	Lime.	Mag- nesia.
1	Park ore (average)	1.91	76.77	53.74	0.04	0.02	none.	none.	0.14	0.04	0.63	0.24	trace.	99.58	18.51	0.99	0.04	trace.
2*	" " (best rough)	0.47	94.88	66.42	0.03	0.01	"	"	0.10	0.07	0.04	0.34	"	100.39	4.45	trace.	trace.	trace.
3*	" " (fine)	0.68	90.44	63.31	none.	none.	"	"	0.09	0.30	0.30	0.30	"	100.95	8.74	0.24	"	trace.
4	Lindal Moor (blast), No. 1	2.02	78.61	55.03	0.03	0.01	0.04	none.	0.04	trace.	0.24	0.57	0.19	100.05	16.11	1.67	0.03	0.05
5	" " ("), No. 2	1.61	76.05	53.24	0.04	0.02	trace.	trace.	0.03	none.	0.08	0.49	0.14	99.53	18.60	2.04	0.08	0.11
6	" " ("), No. 3	2.68	70.17	49.12	0.04	0.02	0.03	trace.	0.06	0.37	0.31	0.59	trace.	99.49	22.24	2.48	0.24	0.16
7	" " ("), (com- mon).	10.84	65.21	45.65	0.03	0.01	trace.	"	trace.	0.24	1.01	0.41	0.14	100.26	18.67	3.42	0.05	0.04
8*	Lindal Cote (puddling) ...	2.82	77.24	54.07	none.	none.	none.	4.19	0.09	0.24	0.11	6.00	0.41	9.07	7.27	1.47	0.08	trace.
9*	Lindal Moor (puddling), No. 1.	3.35	86.20	60.34	trace.	trace.	0.04	1.43	0.08	0.43	trace.	2.23	0.59	6.50	100.85	5.58	0.58	0.05
10	" " ("), No. 2	2.35	66.60	46.62	"	"	none.	5.96	0.13	0.23	0.07	6.64	1.94	16.28	100.20	14.02	1.76	0.10
11*	Whitrigg's (puddling)	1.97	83.33	58.33	none.	none.	trace.	2.53	0.04	0.02	0.08	4.05	0.15	7.51	99.68	6.55	0.73	0.05
12	Dalton's (blast)	1.80	67.14	47.00	"	"	none.	4.45	trace.	0.25	0.08	6.02	0.15	19.77	99.66	19.09	0.51	0.12
13*	Mouzell Mine (best)	2.28	83.94	58.76	0.03	0.01	"	none.	0.09	0.22	0.28	0.65	none.	13.17	100.66	12.37	0.48	0.09
14	" " (average)	1.40	69.41	48.59	none.	none.	0.03	"	0.06	0.02	0.02	0.44	0.13	27.97	99.48	25.92	1.53	0.07
15	Newton Mine (blast)	3.08	77.64	54.35	trace.	trace.	trace.	"	0.01	0.15	0.13	1.09	0.14	17.94	100.17	15.44	2.13	0.06
16	Urswick (blast)	6.59	61.30	42.91	0.02	0.01	"	"	0.02	0.28	0.24	1.01	0.58	29.73	99.75	26.78	2.54	0.16

* Used for making iron by Bessemer process.

Note. The alkalies were not determined.

FIRST SERIES OF EXPERIMENTS.

TRANSVERSE STRAIN.

EXPERIMENT I. (June 1867).—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1·02 inch square. Length between supports 4 feet 6 inches. Mark on bar, “H 1. Hard Steel.”

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	50	·065		Weight of scale &c. 36 lbs.
2	100	·118		
3	150	·179		
4	200	·240		
5	250	·309		
6	300	·364		
7	350	·426		
8	400	·491		
9	450	·555		
10	500	·611		
11	550	·676		
12	600	·742		
13	650	·803		
14	700	·866		
15	750	·946		
16	800	1·006		
17	850	1·076		
18	900	1·146		
19	950	1·206		
20	1000	1·266		
21	1050	1·346		
22	1100	1·406	·000	
23	1150	1·476	·000	
24	1200	1·546	·016	
25	1250	1·646	·055	
26	1300	1·796	·133	
27	1350	2·156	·429	
28	1400	2·746	·883	Experiment discontinued.

Results of Exp. I.

Here the weight (w) at the limit of elasticity is 1210 lbs., and the corresponding deflection (δ) is 1·546.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001308.

By formula (7).—The mean value of the modulus of elasticity (E) = 30,096,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 33,830,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 77·944.

By formula (9).—Work of deflection (u) for unity of section = 77·917.

By formula (12).—Value of C , the unit of working strength = 6·860 tons.

TRANSVERSE STRAIN.

EXP. II.—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar .995 inch square. Length between supports 4 feet 6 inches. Mark on bar, "H 2. Medium."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	50	.065		
2	100	.128		
3	150	.201		
4	200	.266		
5	250	.330		
6	300	.396		
7	350	.466		
8	400	.534		
9	450	.601		
10	500	.682	.000	
11	550	.760	.027	
12	600	.880	.052	
13	650	1.020	.115	
14	700	2.040	1.068	
15	750	.....	.....	Bar destroyed.

Results of Exp. II.

Here the weight (w) at the limit of elasticity is 510 lbs., and the corresponding deflection (δ) is .682.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001280.

By formula (7).—The mean value of the modulus of elasticity (E) = 30,754,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 34,443,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 14.242.

By formula (9).—Work of deflection (u) for unity of section = 14.383.

By formula (12).—Value of C , the unit of working strength = 3.108 tons.

TRANSVERSE STRAIN.

Exp. III.—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1·01 inch square. Length between supports 4 feet 6 inches. Mark on bar, "H 3. Soft."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	50	·074		
2	100	·127		
3	150	·195		
4	200	·262		
5	250	·330		
6	300	·395		
7	350	·453		
8	400	·515		
9	450	·577	·000	
10	500	·645	·007	
11	550	·716	·018	
12	600	·793	·019	
13	650	·873	·032	
14	700	1·029	·118	
15	750	1·279	·287	
16	800	2·709	1·625	Experiment discontinued.

Results of Exp. III.

Here the weight (w) at the limit of elasticity is 610 lbs., and the corresponding deflection (δ) is ·793.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001319.

By formula (7).—The mean value of the modulus of elasticity (E) = 29,717,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 32,717,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 20·155.

By formula (9).—Work of deflection (u) for unity of section = 19·757.

By formula (12).—Value of C , the unit of working strength = 3·540 tons.

TRANSVERSE STRAIN.

Exp. IV. (January 1868).—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1·071 inch square. Length between supports 4 feet 6 inches. Mark on bar, “H 1+.”

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·072		Very soft steel.
2	146	·147		
3	202	·200		
4	258	·275		
5	314	·352		
6	370	·430		
7	426	·497		
8	482	·558	·015	
9	538	·635	·015	
10	594	·691	·021	
11	650	·771	·028	
12	706	·891	·053	
13	762	1·437	·586	

Results of Exp. IV.

Here the weight (w) at the limit of elasticity is 660 lbs., and the corresponding deflection (δ) is ·771.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001383.

By formula (7).—The mean value of the modulus of elasticity (E) = 28,460,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 31,740,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 21·20.

By formula (9).—Work of deflection (u) for unity of section = 18·48.

By formula (12).—Value of C , the unit of working strength = 3·228 tons.

TRANSVERSE STRAIN.

Exp. V.—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1·032 inch square. Length between supports 4 feet 6 inches. Mark on bar, “H2+.”

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·120	·000	Soft steel.
2	146	·190	·000	
3	202	·254	·011	
4	258	·324	·012	
5	314	·405	·013	
6	370	·486	·021	
7	426	·554		
8	482	·638		
9	538	·692		
10	594	·780		
11	650	·870		
12	706	·968	·028	
13	762	1·199	·150	
14	818	1·448	·474	

Results of Exp. V.

Here the weight (w) at the limit of elasticity is 716 lbs., and the corresponding deflection (δ) is ·968.

By formula (6).—The mean value of the deflection of unity of pressure and section (D_1) = ·001384.

By formula (7).—The mean value of the modulus of elasticity (E) = 28,440,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 28,610,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 28·28.

By formula (9).—Work of deflection (u) for unity of section = 25·95.

By formula (12).—Value of C , the unit of working strength = 3·938 tons.

TRANSVERSE STRAIN.

EXP. VI.—Bar of Steel from the Hæmatite Steel and Iron Company. Dimension of bar 1·016 inch square. Length between supports 4 feet 6 inches. Mark on bar, "H3+."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·130		Very soft steel.
2	146	·199		
3	202	·274	·009	
4	258	·352	·016	
5	314	·428	·016	
6	370	·505	·020	
7	426	·580	·042	
8	482	·656	·048	
9	538	·734	·048	
10	594	·808	·056	
11	650	·882	·079	
12	706	·990	·798	
13	762	1·530	·998	

Results of Exp. VI.

Here the weight (w) at the limit of elasticity is 660 lbs., and the corresponding deflection (δ) is ·882.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001406.

By formula (7).—The mean value of the modulus of elasticity (E) = 28,000,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 29,080,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 24·25.

By formula (9).—Work of deflection (u) for unity of section = 23·49.

By formula (12).—Value of C , the unity of working strength = 3·781 tons.

TRANSVERSE STRAIN.

Exp. VII.—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1 inch square. Length between supports 4 feet 6 inches. Mark on bar, “H 4+.”

No of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·150	...	Soft steel. Weight remained on bar from 5 P.M. to 10 A.M. The deflection in that time increased by ·004 of an inch.
2	146	·215		
3	202	·285	·044	
4	258	·352	·046	
5	314	·432	·048	
6	370	·498	·054	
7	426	·574		
8	482	·646		
9	538	·734		
10	594	·804		
11	650	·873		
12	706	·968		
13	762	1·136	·151	
14.	818	1·528	·516	

Results of Exp. VII.

Here the weight (w) at the limit of elasticity is 716 lbs., and the corresponding deflection (δ) is ·968.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001330.

By formula (7).—The mean value of the modulus of elasticity (E) = 29,600,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 28,590,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 28·28.

By formula (9).—Work of deflection (u) for unity of section = 28·28.

By formula (12).—Value of C , the unit of working strength = 4·315 tons.

TRANSVERSE STRAIN.

Exp. VIII.—Bar of Steel from the Barrow Hæmatite Steel Company. Dimension of bar 1·051 inch square. Length between supports 4 feet 6 inches. Mark on bar, "H 5+."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·122		Rather harder steel.
2	146	·196		
3	202	·271	·002	
4	258	·348	·002	
5	314	·420	·004	
6	370	·493	·006	
7	426	·566	·008	
8	481	·648	·010	
9	538	·718	·012	
10	594	·783	·014	
11	650	·848	·016	
12	706	·932		
13	762	1·058		Weight left on from 1 P.M. to 2 P.M.
14	818	1·182	·104	
15	874	1·410	·295	

Results of Exp. VIII.

Here the weight (w) at the limit of elasticity is 772 lbs., and the corresponding deflection (δ) is 1·058.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001658.

By formula (7).—The mean value of the modulus of elasticity (E) = 23,740,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 25,720,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 34·03.

By formula (9).—Work of deflection (u) for unity of section = 30·81.

By formula (12).—Value of C , the unit of working strength = 4·108 tons.

TRANSVERSE STRAIN.

Exp. IX.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Dimension of bar 1.042 inch square. Length between supports 4 feet 6 inches. Mark on bar, "H 6 +."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	.148	.000	This steel is of the same quality as bar S.
2	146	.220	.000	
3	202	.228	.018	
4	258	.360	.018	
5	314	.443	.018	
6	370	.508	.018	
7	426	.578	.022	
8	482	.650	.022	
9	538	.732	.022	
10	594	.798	.022	
11	650	.864	.024	
12	706	.966		
13	762	1.070	.050	
14	818	1.196	.081	Weight left on bar from 4.30 P.M. to 10 A.M.
15	874	1.544	.494	

Results of Exp. IX.

Here the weight (w) at the limit of elasticity is 772 lbs., and the corresponding deflection (δ) is 1.07.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001595.

By formula (7).—The mean value of the modulus of elasticity (E) = 24,680,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 23,550,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 34.42.

By formula (9).—Work of deflection (u) for unity of section = 31.73.

By formula (12).—Value of C , the unit of working strength = 4.112 tons.

TRANSVERSE STRAIN.

Exp. X. (April 1869).—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar 1.018×1.04 inch. Length between supports 4 feet 6 inches. Mark on bar, "1."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	34	.054	...	Hard cast steel.
2	62	.094		
3	118	.162	.006	
4	146	.190	.002	
5	174	.228	.005	
6	314	.436	.004	
7	370	.502	.004	
8	426	.578	.025	
9	454	.614	.026	
10	482	.656	.028	
11	510	.696		
12	538	.730		
13	566	.768		
14	594	.802		
15	622	.860		
16	650	.940		
17	678	.985		
18	706	1.016		
19	762	1.079		
20	818	1.141		
21	874	1.162	.028	
22	930	1.235		
23	986	1.329		
24	1041	1.391		
25	1097	1.443		
26	1153	1.526		
27	1209	1.610		
28	1241	1.693		
29	1321	1.860	.040	

Results of Exp. X.

Here the weight (w) at the limit of elasticity is 1251 lbs., and the corresponding deflection (δ) is 1.693.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001481.

By formula (7).—The mean value of the modulus of elasticity (E) = 26,580,000.

By formula (1).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 26,060,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 88.25.

By formula (9).—Work of deflection (u) for unity of section = 83.410.

By formula (11).—Value of C , the unit of working strength = 6.831 tons.

TRANSVERSE STRAIN.

Exp. XI.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar $1.044 \times .028$ inch. Length between supports 4 feet 6 inches. Mark on bar, "2."

No of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	.120		
2	146	.186	.003	
3	202	.242	.009	
4	258	.312	.009	
5	314	.378	.009	
6	370	.470	.009	
7	424	.546	.010	
8	482	.612	.010	
9	538	.677	.010	
10	594	.744		
11	650	.812		
12	706	.888		
13	762	.952		
14	818	1.016		
15	874	1.084	.011	
16	930	1.154		
17	986	1.212	.014	
18	1042	1.276		
19	1098	1.336		
20	1154	1.398		
21	1210	1.460		
22	1266	1.522		
23	1322	1.615	.016	
24	1378	1.708	.042	
25	1434	1.801	.082	
26	1466	1.933		
27	1522	2.086	.208	
28	1578	3.836	1.836	

Results of Exp. XI.

Here the weight (w) at the limit of elasticity is 1444 lbs., and the corresponding deflection (δ) is 1.801.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001354.

By formula (7).—The mean value of the modulus of elasticity (E) = 29,070,000.

By formula (1).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 29,640,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 108.4.

By formula (9).—Work of deflection (u) for unity of section = 101.1.

By formula (11).—Value of C , the unit of working strength = 7.879 tons.

TRANSVERSE STRAIN.

Exp. XII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar 1.022×1.013 inch. Length between supports 4 feet 6 inches. Mark on bar, "3."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	.144	.000	
2	258	.373	.022	
3	370	.524	.032	
4	482	.672	.026	
5	594	.812	.047	
6	706	.952		
7	762	1.038	.022	
8	828	1.124		
9	884	1.170	.023	
10	940	1.242		
11	996	1.308		
12	1052	1.402		
13	1108	1.464	.021	
14	1164	1.568		
15	1220	1.622	.046	
16	1276	1.722	.062	
17	1332	1.777	.100	
18	1388	1.819	.160	
19	1444	2.652	.842	
20	1556	4.652	2.588	

Results of Exp. XII.

Here the weight (w) at the limit of elasticity is 1398 lbs., and the corresponding deflection (δ) is 1.819.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001419.

By formula (7).—The mean value of the modulus of elasticity (E) = 27,740,000.

By formula (1).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 26,160,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 105.9.

By formula (9).—Work of deflection (u) for unity of section = 102.3.

By formula (11).—Value of C , the unit of working strength = 8.028 tons.

TRANSVERSE STRAIN.

Exp. XIII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar $1\cdot008 \times 1\cdot012$ inch. Length between supports 4 feet 6 inches. Mark on bar, “4.”

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	·108		
2	314	·406		
3	538	·686		
4	762	·975		
5	874	1·090		
6	986	1·198		
7	1042	1·304		
8	1098	1·408		
9	1154	1·459		
10	1210	1·543		
11	1266	1·592	·001	
12	1322	1·676	·012	
13	1378	1·769	·046	
14	1434	1·908	·094	
15	1490	2·428	·572	

Results of Exp. XIII.

Here the weight (w) at the limit of elasticity is 1388 lbs., and the corresponding deflection (δ) is 1·769.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = ·001295.

By formula (7).—The mean value of the modulus of elasticity (E) = 30,400,000.

By formula (1).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 35,120,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 102·3.

By formula (9).—Work of deflection (u) for unity of section = 100·3.

By formula (11).—Value of C , the unit of working strength = 8·094 tons.

TRANSVERSE STRAIN.

Exp. XIV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar 1.025×1.02 inch. Length between supports 4 feet 6 inches. Mark on bar, "5."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	.117	.000	
2	146	.193	.009	
3	202	.257	.009	
4	258	.328	.009	
5	314	.403	.009	
6	370	.477	.009	
7	426	.540	.010	
8	482	.608	.010	
9	538	.673	.010	
10	650	.816	.010	
11	762	.977	.010	
12	818	1.057	.012	
13	874	1.113	.012	
14	930	1.189	.011	
15	986	1.263	.007	
16	1042	1.325	.008	
17	1098	1.387	.009	
18	1154	1.457	.010	
19	1210	1.543	.015	
20	1266	1.607	.017	
21	1322	1.760	.023	
22	1378	1.928	.029	
23	1434	2.188	.073	
24	1490	2.339	.161	
25	1546	2.690	.797	

Results of Exp. XIV.

Here the weight (w) at the limit of elasticity is 1276 lbs., and the corresponding deflection (δ) is 1.607.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001351.

By formula (7).—The mean value of the modulus of elasticity (E) = 29,140,000.

By formula (1).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 31,140,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 85.44.

By formula (9).—Work of deflection (u) for unity of section = 81.60.

By formula (11).—Value of C , the unit of working strength = 7.209 tons.

TRANSVERSE STRAIN.

Exp. XV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Dimension of bar 1.02×1.02 inch. Length between supports 4 feet 6 inches. Mark on bar, "6."

No. of Exp.	Weight laid on, in lbs.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1	90	.132	.000	
2	146	.200	.013	
3	202	.268	.016	
4	258	.331	.019	
5	314	.406	.019	
6	370	.474	.019	
7	426	.550	.023	
8	482	.610		
9	538	.680	.018	
10	594	.774	.020	
11	650	.854	.024	
12	706	.926		
13	762	.994	.014	
14	818	1.078	.014	
15	874	1.142		
16	930	1.208		
17	986	1.274	.015	
18	1042	1.344		
19	1098	1.440		
20	1154	1.502	.016	
21	1210	1.578	.022	
22	1266	1.719	.037	
23	1322	1.753	.072	
24	1378	1.866	.078	
25	1434	2.003	.158	
26	1490	3.378	1.378	

Results of Exp. XV.

Here the weight (w) at the limit of elasticity is 1220 lbs., and the corresponding deflection (δ) is 1.578.

By formula (6).—The mean value of the deflection for unity of pressure and section (D_1) = .001372.

By formula (7).—The mean value of the modulus of elasticity (E) = 28,690,000.

By formula (2).—The modulus of elasticity (E) corresponding to 112 lbs. pressure = 27,590,000.

By formula (8).—Work of deflection (U) up to the limit of elasticity = 80.21.

By formula (9).—Work of deflection (u) for unity of section = 77.13.

By formula (12).—Value of C , the unit of working strength = 6.925 tons.

Summary of Results of the Experiments on Transverse Strain.

No. of experiment.	Manufacturer.	Mark on Bar.	Date of Experiment.	Mean value (D.) of the deflection for unit of pressure and section. By eq. (6).	Mean value (E) of the modulus of elasticity By eq. (7).	Modulus of elasticity (E) corresponding to 112 lbs. pressure. By eq. (1 & 2).	Work of deflection (U) up to the limit of elasticity. By eq. (8).	Work of deflection (v) for unit of section. By eq. (9).	Value of C, the unit of working strength. By eq. (11 & 12).
1	The Barrow Hæmatite Steel Company	H 1	June 1867	·001308	30,096,000	33,830,000	77,944	77,917	6,860
2		H 2	"	·001280	30,754,000	34,443,000	14,242	14,383	3,108
3		H 3	"	·001319	29,717,000	32,717,000	20,155	19,757	3,540
4	The Barrow Hæmatite Steel Company	H 1 +	January 1868	·001383	28,460,000	31,740,000	21,200	18,480	3,228
5		H 2 +	"	·001384	28,440,000	28,610,000	28,280	25,950	3,938
6		H 3 +	"	·001406	28,000,000	29,080,000	24,250	23,490	3,781
7		H 4 +	"	·001330	29,600,000	28,590,000	28,280	28,280	4,315
8		H 5 +	"	·001658	23,740,000	25,720,000	34,030	30,810	4,108
9		H 6 +	"	·001595	24,680,000	23,550,000	34,420	31,730	4,112
10	The Heaton Steel Company	1	April 1869	·001481	26,580,000	26,060,000	88,250	83,410	6,831
11		2	"	·001354	29,070,000	29,640,000	108,400	101,100	7,879
12		3	"	·001419	27,740,000	26,160,000	105,900	102,300	8,028
13		4	"	·001295	30,400,000	35,120,000	102,300	100,200	8,094
14		5	"	·001351	29,140,000	31,140,000	85,440	81,600	7,209
15		6	"	·001372	28,690,000	27,590,000	80,210	77,130	6,925

SECOND SERIES OF EXPERIMENTS.

TENSILE STRAIN.

EXP. I. (June 1867).—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 1." Diameter of specimen $\cdot 744$ inch. Area $\cdot 4347$ square inch. Reduced diameter after fracture $\cdot 744$ inch. Area $\cdot 4347$ square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	10249	....	....			
2	11929	....	....			
3	13609	....	....			
4	15289	....	....			
5	16969	....	....			
6	18649	....	....			
7	20329	....	....			
8	22219	....	....			
9	23899	....	....	$\cdot 0062$	$\cdot 0031$	
10	27259	....	....	$\cdot 0063$	$\cdot 0031$	
11	30619	....	....	$\cdot 0065$	$\cdot 0031$	
12	32299	....	....	$\cdot 0125$	$\cdot 0093$	
13	33979	....	....	$\cdot 0163$	$\cdot 0101$	
14	35659	....	....	$\cdot 0218$	$\cdot 0171$	
15	37339	....	....	$\cdot 0375$	$\cdot 0312$	
16	39019	....	....	$\cdot 0406$	$\cdot 0390$	
17	40594	93383	41.700	....	....	Broke in neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 93,383 lbs., or 41.7 tons, and the corresponding elongation (l_1) is $\cdot 0406$. By formula (13).—The work (u) expended in producing rupture = 1895.

EXP. II.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 2." Diameter of specimen $\cdot 69$ inch. Area $\cdot 3754$ square inches. Reduced diameter after fracture $\cdot 66$ inch. Area $\cdot 3401$ square inch.

1	15289	....	....	$\cdot 0062$		
2	18649	....	....	$\cdot 0195$	$\cdot 0178$	
3	22009	....	....	$\cdot 0312$	$\cdot 0226$	
4	25369	....	....	$\cdot 0522$	$\cdot 0515$	
5	27049	....	....	$\cdot 0656$	$\cdot 0647$	
6	28729	....	....	$\cdot 0866$	$\cdot 0863$	
7	30309	80724	36.030	....	....	Broke in centre.

Results.—Here the breaking-strain (P_1) per square inch of section is 80,724 lbs., or 36.03 tons, and the corresponding elongation (l_1) is $\cdot 0866$. By formula (13).—The work (u) expended in producing rupture = 3495.

EXP. III.—Bar of Steel from the Barrow Haematite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 3." Diameter of specimen $\cdot 75$ inch. Area $\cdot 4417$ square inch. Reduced diameter after fracture $\cdot 542$ inch. Area $\cdot 2306$ square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	15289	....	....	$\cdot 0012$		
2	18049	....	....	$\cdot 0180$		
3	22009	....	....	$\cdot 0290$	$\cdot 0163$	
4	25369	....	....	$\cdot 0656$	$\cdot 0622$	
5	28729	....	....	$\cdot 0656$	$\cdot 0622$	[neck.
6	30304	68607	30.63	....	....	Broke $1\frac{1}{2}$ inch from

Results.—Here the breaking-strain (P_1) per square inch of section is 68,607 lbs., or 30.63 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 0656$. By formula (13).—The work (u) expended in producing rupture = 2250.

EXP. IV. (January 1868).—Bar of Steel from the Barrow Haematite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 1 +." Diameter of specimen $\cdot 763$ inch. Area $\cdot 4572$ square inch. Reduced diameter after fracture $\cdot 51$ inch. Area $\cdot 2043$ square inch.

1	15289	....	....	$\cdot 0006$		
2	18649	....	....	$\cdot 0062$		
3	20329	....	....	$\cdot 0222$	$\cdot 0195$	
4	22009	....	....	$\cdot 0281$	$\cdot 0265$	
5	23689	....	....	$\cdot 0375$	$\cdot 0343$	
6	25369	....	....	$\cdot 0546$	$\cdot 0483$	
7	27049	....	....	$\cdot 0765$	$\cdot 0733$	
8	28729	....	....	$\cdot 1858$	$\cdot 1765$	
9	30304	66281	29.59	....	....	Broke in centre.

Results.—Here the breaking-strain (P_1) per square inch of section is 66,281 lbs., or 29.59 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 1858$. By formula (13).—The work (u) expended in producing rupture = 6157.

Exp. V.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, “H 2+.” Diameter of specimen $\cdot 764$ inch. Area $\cdot 4584$ square inch. Reduced diameter after fracture $\cdot 568$ inch. Area $\cdot 2696$ square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation	Permanent set.	
	lbs.	lbs.	tons.			
1	15289	....	....			
2	18649	....	....			
3	22009	....	....	$\cdot 0003$		
4	23689	....	....	$\cdot 0004$	$\cdot 0003$	
5	25369	....	....	$\cdot 0118$	$\cdot 0106$	
6	27049	....	....	$\cdot 0137$	$\cdot 0125$	
7	28729	....	....	$\cdot 0171$	$\cdot 0156$	
8	30304	....	....	$\cdot 0233$	$\cdot 0218$	
9	32014	....	....	$\cdot 0312$	$\cdot 0296$	[from centre.
10	33574	73241	32·69	....	....	Broke 2 inches

Results.—Here the breaking-strain (P_1) per square inch of section is 73,241 lbs., or 32·69 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 0312$. By formula (13).—The work (u) expended in producing rupture = 1142.

Exp. VI.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, “H 3+.” Diameter of specimen $\cdot 771$ inch. Area $\cdot 4656$ square inch. Reduced diameter after fracture $\cdot 598$ inch. Area $\cdot 2808$ square inch.

1	15289	....	....	$\cdot 0053$		
2	18649	....	....	$\cdot 0116$		
3	20329	....	....	$\cdot 0187$	$\cdot 0171$	
4	22009	....	....	$\cdot 0265$	$\cdot 0187$	
5	23689	....	....	$\cdot 0321$	$\cdot 0250$	
6	25369	....	....	$\cdot 0375$	$\cdot 0296$	
7	27049	....	....	$\cdot 0450$	$\cdot 0437$	
8	28729	....	....	$\cdot 0718$	$\cdot 0593$	
9	30304	....	....	$\cdot 0812$	$\cdot 0786$	[from neck.
10	32014	68758	30·69	....	....	Broke $1\frac{1}{2}$ inch

Results.—Here the breaking-strain (P_1) per square inch of section is 68,758 lbs., or 30·69 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 0812$. By formula (13).—The work (u) expended in producing rupture = 2791.

Exp. VII.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 4+." Diameter of specimen .768 inch. Area .4639 square inch. Reduced diameter after fracture .768 inch. Area .4639 square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	18649	....	....	.0031		
2	22009	....	....	.0108		
3	23689	....	....	.0226	.0187	
4	25369	....	....	.0297	.0222	
5	27069	....	....	.0343	.0375	
6	28729	....	....	.0438	.0421	
7	30304	....	....	.0500	.0491	
8	32014	....	....	.0671	.0622	
9	33574	....	....	.0906	.0875	
10	35334	75736	33.81	....	....	Broke in neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 75,736 lbs., or 33.81 tons, and the corresponding elongation (l_1) per unit of length is .0906. By formula (13).—The work (u) expended in producing rupture = 3430.

Exp. VIII.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 5+." Diameter of specimen .76 inch. Area .4536 square inch. Reduced diameter after fracture .558 inch. Area .2366 square inch.

1	18649	....	....	.0027		
2	22009	....	....	.0062		
3	25369	....	....	.0296	.0250	
4	27049	....	....	.0375	.0312	
5	28729	....	....	.0467	.0437	
6	30304	....	....	.0622	.0562	
7	32014	....	....	.0765	.0750	
8	33574	74016	33.04	....	....	[centre. Broke 1 inch from

Results.—Here the breaking-strain (P_1) per square inch of section is 74,016 lbs., or 33.04 tons, and the corresponding elongation (l_1) per unit of length is .0765. By formula (13).—The work (u) expended in producing rupture = 2831.

Exp. IX.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Elongations taken on 8 inches length. Mark on bar, "H 6+." Diameter of specimen $\cdot 772$ inch. Area $\cdot 4677$ square inch. Reduced diameter after fracture $\cdot 581$ inch. Area $\cdot 3651$ square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	18649	....	....	$\cdot 0003$		
2	22009	....	....	$\cdot 0062$		
3	25369	....	....	$\cdot 0250$	$\cdot 0218$	
4	27049	....	....	$\cdot 0335$	$\cdot 0281$	
5	28728	....	....	$\cdot 0406$	$\cdot 0375$	
6	30304	....	....	$\cdot 0500$	$\cdot 0468$	
7	31864	....	....	$\cdot 0686$	$\cdot 0678$	
8	33424	....	....	$\cdot 1000$	$\cdot 0937$	
9	35124	75120	33 $\cdot$ 53	....	....	Broke in centre.

Results.—Here the breaking-strain (P_1) per square inch of section is 75,120 lbs., or 33 $\cdot$ 53 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 1$. By formula (13).—The work (u) expended in producing rupture = 3756.

Exp. X. (April 1869).—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "1." Diameter of specimen $\cdot 748$ inch. Area $\cdot 4394$ square inch. Reduced diameter after fracture $\cdot 748$ inch. Area $\cdot 4394$ square inch.

1	16969	....	....	$\cdot 000$		
2	23689	....	....	$\cdot 000$		
3	27049	....	....	$\cdot 000$		
4	29119	....	....	$\cdot 000$		
5	30799	....	....	$\cdot 000$		
6	32479	....	....	$\cdot 0012$		
7	34039	....	....	$\cdot 0156$		
8	35659	....	....	$\cdot 0208$		
9	37189	....	....	$\cdot 0235$	$\cdot 0208$	
10	38704	....	....	$\cdot 0351$	$\cdot 0315$	
11	40264	....	....	$\cdot 0390$	$\cdot 0351$	
12	41104	93545	41 $\cdot$ 761	....	....	Broke in neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 93,545 lbs., or 41 $\cdot$ 761 tons, and the corresponding elongation (l_1) per unit of length is $\cdot 0390$. By formula (13).—The work (u) expended in producing rupture = 1824.

EXP. XI.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "2." Diameter of specimen .758 inch. Area .4512 square inch. Reduced diameter after fracture .758 inch. Area .4512 square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	16969	....	....	.0019		
2	23479	....	....	.0024		
3	28669	....	....	.0024		
4	32119	....	....			
5	35479	....	....	.0125	.0103	
6	38839	....	....	.0235	.0187	
7	40519	....	....	.0312	.0235	
8	42199	93526	41.752	....	....	Broke in neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 93,526 lbs., or 41.752 tons, and the corresponding elongation (l_1) per unit of length is .0312. By formula (13).—The work (u) expended in producing rupture = 1459.

EXP. XII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "3." Diameter of specimen .746 inch. Area .4370 square inch. Reduced diameter after fracture .626 inch. Area .3077 square inch.

1	16969					
2	22144					
3	26149	....	....	.0019		
4	29794	....	....	.0038		
5	32944	....	....			
6	36019	....	....	.0157	.0125	
7	37699	....	....	.0208	.0157	
8	39379	....	....	.0234	.0227	
9	41059	....	....	.0277	.0250	
10	41899	....	....	.0312	.0250	
11	42739	....	....	.0375	.0253	
12	43379	....	....	....	.0390	
13	44419	....	....			
14	45259	....	....	.0416	.0400	
15	46699	....	....	.0468	.0416	
16	46939	....	....	.0520	.0452	
17	47359	....	....	.0582	.0512	
18	47779	....	....	.0625		
19	48199	....	....	.0645	.0580	
20	48619	....	....	.0781	.0728	
21	49039	....	....	.0937	.0750	
22	49459	113178	50.526	....	....	[centre. Broke 2 ins. from

Results.—Here the breaking-strain (P_1) per square inch of section is 113,178 lbs., or 50.526 tons, and the corresponding elongation (l_1) per unit of length is .0937. By formula (13).—The work (u) expended in producing rupture = 5302.

Exp. XIII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "4." Diameter of specimen .746 inch. Area .4370 square inch. Reduced diameter after fracture .746 inch. Area .4370 square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	16969	....	....			
2	27484	....	....			
3	35459	....	....	.0019		
4	39224	....	....	.0208	.0131	
5	40784	....	....	.0234	.0206	
6	41628	....	....	.0250		
7	43308	....	....	.0274		
8	44988	....	....	.0364	.0312	
9	45828	104869	46.816	....	....	Broke in neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 104,869 lbs., or 46.816 tons, and the corresponding elongation (l_1) per unit of length is .0364. By formula (13).—The work (u) expended in producing rupture=1908.

Exp. XIV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "5." Diameter of specimen .754 inch. Area .4465 square inch. Reduced diameter after fracture .754 inch. Area .4465 square inch.

1	24049	....	....	.0038		
2	33629	....	....	.0208		
3	40784	....	....	.0393	.0307	
4	42464	....	....	.0646		
5	43304	....	....	.0781	.0750	
6	43724	....	....	.0937	.0821	
7	44144	98866	44.136	....	....	Broke near neck.

Results.—Here the breaking-strain (P_1) per square inch of section is 98,866 lbs., or 44.136 tons, and the corresponding elongation (l_1) per unit of length is .0937. By formula (13).—The work (u) expended in producing rupture=4631.

Exp. XV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Elongations taken on 8 inches length. Mark on bar, "G." Diameter of specimen $\cdot754$ inch. Area $\cdot4465$ square inch. Reduced diameter after fracture $\cdot528$ inch. Area $\cdot2560$ square inch.

No. of Exp.	Weight laid on.	Breaking-strain per square inch of section.		Per unit of length.		Remarks.
				Elongation.	Permanent set.	
	lbs.	lbs.	tons.			
1	24049	....	....	$\cdot0038$		
2	32629	....	....			
3	39784	....	....	$\cdot0412$	$\cdot0375$	
4	41464	....	....	$\cdot0468$	$\cdot0419$	
5	42304	....	....	$\cdot0500$	$\cdot0450$	
6	43144	....	....	$\cdot0500$		
7	43984	....	....	$\cdot0520$		
8	44824	....	....	$\cdot0663$		
9	45244	....	....	$\cdot0693$	$\cdot0663$	
10	45664	....	....	$\cdot0702$		
11	46504	....	....	$\cdot1041$	$\cdot1012$	[neck.
12	46924	105093	46·915	....	....	Broke 2 ins. from

Results.—Here the breaking-strain (P_1) per square inch of section is 105,093 lbs., or 46·915 tons, and the corresponding elongation (l_1) per unit of length is $\cdot1041$. By formula (13).—The work (u) expended in producing rupture = 5464.

Summary of Results of the Experiments on Tensile Strain.

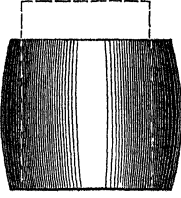
No. of Exp.	Manufacturer.	Mark on Bar.	Date of experiment.	Specific gravity of Specimen.	Weight laid on.	Breaking-strain per square inch of section.		Corresponding elongation per unit of length.	Value of $\frac{1}{2}$ or work producing rupture. By eq. (13).	Remarks.
1	The Barrow Hematite Steel Co	H 1	June 1867	77006	lbs. 40594	lbs.	tons.			
2		H 2		77710	30309	93383	41.700	.0406	1895	Broke in neck.
3		H 3		77899	30304	80724	36.030	.0866	3495	Broke in centre.
4	The Barrow Hematite Steel Co.	H 1+	Jan. 1868	77037	30304	66281	29.590	.1838	6157	Broke in centre.
5		H 2+		77978	33574	72341	32.690	.0312	1142	Broke 2 ins. from centre.
6		H 3+		77952	32014	68758	30.690	.0812	2791	Broke 1½ in. from neck.
7		H 4+		77956	35334	75736	33.810	.0906	3430	Broke in neck.
8		H 5+		78654	33574	74016	33.040	.0765	2831	Broke 1 in. from centre.
9		H 6+		78159	35124	75120	33.530	.1000	3736	Broke in centre.
10	The Heaton Steel Company.....	1	April 1869	78225	41104	93545	41.761	.0390	1824	Broke in neck.
11		2		78176	42199	93526	41.752	.0312	1459	"
12		3		78153	49459	11378	50.526	.0937	5322	Broke 2 ins. from centre.
13		4		78003	45828	104869	46.816	.0364	1908	Broke in neck.
14		5		78128	44144	98866	44.136	.0937	4631	Broke near neck.
15		6		78166	46924	105993	46.915	.1041	5464	Broke 2 ins. from neck.

THIRD SERIES OF EXPERIMENTS.

COMPRESSIVE STRAIN.

EXP. I. (June 1867).—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Mark on bar, "H 1."

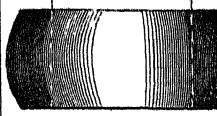
	Before experiment.	After experiment.
Height of specimen	·981 inch.....	·784 inch.
Diameter of specimen	·72 inch	·854 inch.
Area of specimen	·4071 sq. in.	·5728 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	37438	16·713	91951	41·049	·033	 No cracks.
2	44966	20·074	110440	49·303	·042	
3	52166	23·288	128124	57·198	·050	
4	58950	26·316	144786	64·637	·066	
5	66022	29·474	162156	72·391	·075	
6	73134	32·649	179722	80·233	·100	
7	80214	35·809	197023	87·952	·133	
8	88134	39·345	216465	96·636	·187	
9	91840	41·000	225568	100·700	·200	

Results.—Here the strain persquare inch (P_1) causing rupture is 225,568lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·2. By formula (13).—The work (u) expended in producing rupture = 22556.

EXP. II.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Mark on bar, "H 2."

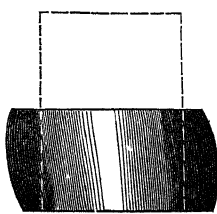
	Before experiment.	After experiment.
Height of specimen	·971 inch.....	·498 inch.
Diameter of specimen	·72 inch	1·066 inch.
Area of specimen	·4071 sq. in.	·8922 sq. in.

1	37438		91951	40·049	·100	 No cracks.
	lbs.	tons.				
2	44966	20·074	110440	49·303	·133	
3	52166	23·288	128124	57·198	·200	
4	58950	26·316	144786	64·637	·266	
5	66022	29·474	162156	72·391	·310	
6	73134	32·649	179722	80·233	·350	
7	80214	35·809	197023	87·952	·400	
8	88134	39·345	216465	96·636	·425	
9	91840	41·000	225568	100·700	·450	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·45. By formula (13).—The work (u) expended in producing rupture = 50752.

Exp. III.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 3."

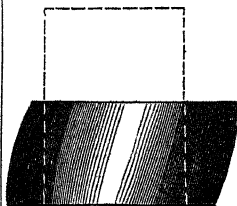
		Before experiment.	After experiment.
Height of specimen	.....	·968 inch.....	·536 inch.
Diameter of specimen	.....	·72 inch	1·065 inch.
Area of specimen	.....	·4071 sq. in.	·8906 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	37438	16·713	91951	41·049	·100	
2	44966	20·074	110440	49·303	·153	
3	52166	23·288	128124	57·198	·210	
4	58950	26·316	144786	64·637	·275	
5	66022	29·474	162156	72·391	·312	
6	73134	32·649	179722	80·233	·350	
7	80214	35·809	197023	87·952	·400	
8	88134	39·345	216465	96·636	·412	
9	91840	41·000	225568	100·700	·450	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·45. By formula (13).—The work (u) expended in producing rupture = 50752.

Exp. IV. (January 1868).—Bar of Steel from the Barrow Hæmatite Steel and Iron Company. Mark on bar, "H 1+."

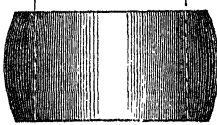
		Before experiment.	After experiment.
Height of specimen	.....	1·00 inch	·51 inch.
Diameter of specimen	.....	·72 inch	1·08 inch.
Area of specimen	.....	·4071 sq. in.	·9175 sq. in.

1	37438	16·713	91951	41·049	·160	
2	44966	20·074	110440	49·303	·160	
3	52166	23·288	128124	57·198	·220	
4	58950	26·316	144786	64·637	·283	
5	66022	29·474	162156	72·391	·340	
6	73134	32·649	179722	80·233	·383	
7	80214	35·809	197023	87·952	·425	
8	88134	39·345	216465	96·636	·475	
9	91840	41·000	225568	100·700	·480	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·48. By formula (13).—The work (u) expended in producing rupture = 54136.

EXP. V.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 2+."

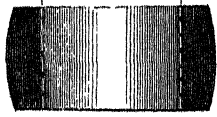
	Before experiment.	After experiment.
Height of specimen	·981 inch.	·553 inch.
Diameter of specimen	·72 inch.	1·02 inch.
Area of specimen	·4071 sq. in.	·8168 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	37438	16·713	91951	41·049	·092	
2	44966	20·074	110440	49·303	·120	
3	52166	23·288	128124	57·198	·175	
4	58950	26·316	144786	64·637	·220	
5	66022	29·474	162156	72·391	·283	
6	73134	32·649	179722	80·233	·325	
7	80214	35·809	197023	87·952	·380	
8	88134	39·345	216465	96·636	·412	
9	91840	41·000	225568	100·700	·525	
						No cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·525. By formula (13).—The work (u) expended in producing rupture = 59211.

EXP. VI.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 3+."

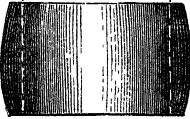
	Before experiment.	After experiment.
Height of specimen	·97 inch.	·504 inch.
Diameter of specimen	·72 inch.	1·07 inch.
Area of specimen	·4071 sq. in.	·8984 sq. in.

1	37438	16·713	91951	41·049	·100	
2	44966	20·074	110440	49·303	·160	
3	52166	23·288	128124	57·198	·220	
4	58950	26·316	144786	64·637	·257	
5	66022	29·474	162156	72·391	·325	
6	73134	32·649	179722	80·233	·374	
7	80214	35·809	197023	87·952	·410	
8	88134	39·345	216465	96·636	·450	
9	91840	41·000	225568	100·700	·474	
						Slight cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·474. By formula (13).—The work (u) expended in producing rupture = 53459.

EXP. VII.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 4+."

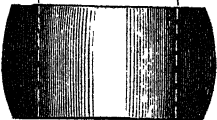
	Before experiment.	After experiment.
Height of specimen.....	·974 inch.	 ·581 inch.
Diameter of specimen.....	·72 inch.	 1·01 inch.
Area of specimen	·4071 sq. in.	 ·8011 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	37438	16·713	91951	41·049	·075	
2	44966	20·074	110440	49·303	·100	
3	52166	23·288	128124	57·198	·133	
4	58950	26·316	144786	64·637	·190	
5	66022	29·474	162156	72·391	·225	
6	73134	32·649	179722	80·233	·295	
7	80214	35·809	197023	87·952	·325	
8	88134	39·345	216465	96·636	·375	
9	91840	41·000	225568	100·700	·392	
						No cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·392. By formula (13).—The work (u) expended in producing rupture = 44211.

EXP. VIII.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 5+."

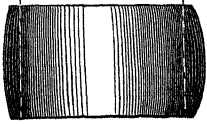
	Before experiment.	After experiment.
Height of specimen.....	·968 inch.	 ·58 inch.
Diameter of specimen.....	·72 inch.	 ·996 inch.
Area of specimen	·4071 sq. in.	 ·7791 sq. in.

1	37438	16·713	91951	41·049	·087	
2	44966	20·074	110440	49·303	·100	
3	52166	23·288	128124	57·198	·137	
4	58950	26·316	144786	64·637	·190	
5	66022	29·474	162156	72·391	·233	
6	73134	32·649	179722	80·233	·288	
7	80214	35·809	197023	87·952	·325	
8	88134	39·345	216465	96·636	·375	
9	91840	41·000	225568	100·700	·400	
						No cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·4. By formula (13).—The work (u) expended in producing rupture = 45113.

EXP. IX.—Bar of Steel from the Barrow Hæmatite Steel and Iron Company.
Mark on bar, "H 6 +."

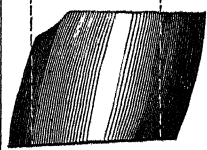
	Before experiment.	After experiment.
Height of specimen	·985 inch.	·586 inch.
Diameter of specimen	·72 inch.	1·012 inch.
Area of specimen	·4071 sq. in.	·8042 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	37438	16·713	91951	41·049	·075	 No cracks.
2	44966	20·074	110440	49·303	·100	
3	52166	23·288	128124	57·198	·150	
4	58950	26·316	144786	64·637	·200	
5	66022	29·474	162156	72·391	·260	
6	73134	32·649	179722	80·233	·300	
7	80214	35·809	197023	87·952	·320	
8	88134	39·345	216465	96·636	·383	
9	91840	41·000	225568	100·700	·400	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·4. By formula (13).—The work (w) expended in producing rupture = 45113.

EXP. X. (April 1869).—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, "1."

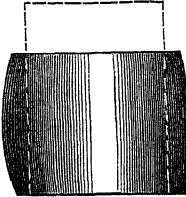
	Before experiment.	After experiment.
Height of specimen	1·00 inch.	·723 inch.
Diameter of specimen	·72 inch.	·906 inch.
Area of specimen	·4071 sq. in.	·6448 sq. in.

No.	Weight laid		Weight laid		Com- pression,	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19·913	109572	48·916	·030	 No cracks.
2	52158	23·284	128366	57·366	·040	
3	59646	26·627	146514	65·408	·065	
4	68942	30·777	169349	75·602	·130	
5	76110	33·977	186956	83·462	·215	
6	82382	36·777	202363	90·340	·290	
7	85070	37·977	208965	93·288	·300	
8	86862	39·670	213367	95·253	·315	
9	91840	41·000	225568	100·700	·333	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·333. By formula (13).—The work (w) expended in producing rupture = 37557.

Exp. XI.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, “2.”

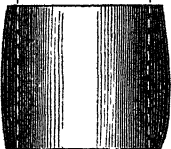
	Before experiment.	After experiment.
Height of specimen.....	1.00 inch.	.74 inch.
Diameter of specimen.....	.72 inch.	.908 inch.
Area of specimen	.4071 sq. in.	.6475 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19.913	109572	48.916	.060	
2	52030	23.227	127806	57.056	.080	
3	59102	26.384	145178	64.811	.110	
4	66662	29.759	163748	73.101	.150	
5	74390	33.209	182731	81.576	.200	
6	81558	36.409	200339	89.437	.240	
7	88726	39.609	217946	97.297	.270	
8	92840	41.000	225568	100.700	.288	
						No cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100.7 tons, and the corresponding compression (l_1) per unit of length is .288. By formula (13).—The work (u) expended in producing rupture = 32481.

Exp. XII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, “3.”

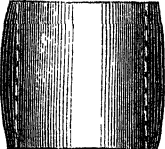
	Before experiment.	After experiment.
Height of specimen.....	1.00 inch.	.76 inch.
Diameter of specimen.....	.72 inch.	.866 inch.
Area of specimen	.4071 sq. in.	.5898 sq. in.

	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19.913	109572	48.916	.060	
2	52030	23.227	127806	57.056	.070	
3	59102	26.384	145178	64.811	.090	
4	66662	29.759	163748	73.101	.120	
5	74390	33.209	182731	81.576	.170	
6	81558	36.409	200339	89.437	.200	
7	88726	39.609	217946	97.297	.230	
8	91840	41.000	225568	100.700	.257	
						No cracks.

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100.7 tons, and the corresponding compression (l_1) per unit of length is .257. By formula (13).—The work (u) expended in producing rupture = 28985.

EXP. XIII.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, "4."

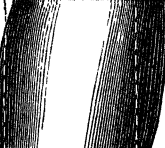
	Before experiment.	After experiment.
Height of specimen.....	1.00 inch.	.784 inch.
Diameter of specimen.....	.72 inch.	.864 inch.
Area of specimen	.4071 sq. in.	.5863 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19.913	109572	48.916	.050	 No cracks.
2	52030	23.227	127806	57.056	.070	
3	59102	26.384	145178	64.811	.080	
4	66662	29.759	163748	73.101	.120	
5	74390	33.209	182731	81.576	.160	
6	81558	36.409	200339	89.437	.190	
7	88726	39.609	217946	97.297	.230	
8	91840	41.000	225568	100.700	.247	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100.7 tons, and the corresponding compression (l_1) per unit of length is .247. By formula (13).—The work (u) expended in producing rupture = 27857.

EXP. XIV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, "5,"

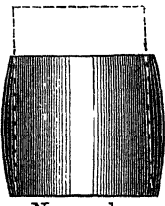
	Before experiment.	After experiment.
Height of specimen.....	1.00 inch.	.78 inch.
Diameter of specimen.....	.72 inch.	.87 inch.
Area of specimen	.4071 sq. in.	.5944 sq. in.

No.	Weight laid		Weight laid		Com- pression,	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19.913	109572	48.916	.050	 No cracks.
2	52030	23.227	127806	57.056	.070	
3	59102	26.384	145178	64.811	.090	
4	66662	29.759	163748	73.101	.120	
5	74390	33.209	182731	81.576	.106	
6	81558	36.409	200339	89.437	.200	
7	88726	39.609	217946	97.297	.240	
8	91840	41.000	225568	100.700	.257	

Results.—Here the strain per square inch (P_1) causing rupture is 225,568 lbs., or 100.7 tons, and the corresponding compression (l_1) per unit of length is .257. By formula (13).—The work (u) expended in producing rupture = 28985.

EXP. XV.—Bar of Steel from the Heaton Steel and Iron Company, Langley Mills. Mark on bar, "6."

	Before experiment.	After experiment.
Height of specimen	1·00 inch.	·734 inch.
Diameter of specimen	·72 inch.	·903 inch.
Area of specimen	·4071 sq. in.	·5404 sq. in.

No. of Exp.	Weight laid on specimen.		Weight laid on per square inch of section.		Com- pression, in inches.	Remarks.
	lbs.	tons.	lbs.	tons.		
1	44606	19·913	109572	48·916	·060	
2	52030	23·227	127806	57·056	·080	
3	59102	26·384	145178	64·811	·110	
4	66662	29·759	163748	73·101	·150	
5	74390	33·209	182731	81·576	·190	
6	81558	36·409	200339	89·437	·230	
7	88726	39·609	217946	97·297	·270	
8	91840	41·000	225568	100·700	288	

Results.—Here the strain per square inch (P_1) causing rupture is 225·568 lbs., or 100·7 tons, and the corresponding compression (l_1) per unit of length is ·288. By formula (13).—The work (u) expended in producing rupture = 32481.

Summary of Results of the Experiments on Compression.

No. of Exp.	Manufacturer.	Mark on bar.	Date of Exp.	Greatest weight laid on per square inch of section.		Corresponding compression per unit of length.	Value of ν , or work expended in crushing the bar. By eq. (13).	Remarks.
1	The Barrow Hæmatite Steel Co.	H 1	June 1867	lbs.	tons.		22556	No cracks.
2		H 2	" "	225568	100'700	'200	50752	" "
3		H 3	" "	225568	100'700	'450	50752	" "
4	The Barrow Hæmatite Steel Co.	H 1 +	Jan. 1868	225568	100'700	'480	54136	No cracks.
5		H 2 +	" "	225568	100'700	'525	59211	" "
6		H 3 +	" "	225568	100'700	'474	53459	Slight cracks.
7		H 4 +	" "	225568	100'700	'392	44211	No cracks.
8		H 5 +	" "	225568	100'700	'400	45113	" "
9		H 6 +	" "	225568	100'700	'400	45113	" "
10	The Heaton Steel Company	1	April 1869	225568	100'700	'333	37557	No cracks.
11		2	" "	225568	100'700	'288	32481	" "
12		3	" "	225568	100'700	'257	28085	" "
13		4	" "	225568	100'700	'247	27857	" "
14		5	" "	225568	100'700	'257	28985	" "
15		6	" "	225568	100'700	'288	32481	" "

Abstract of Experiments on Hæmatite Steel.

The strength of these bars, owing to their flexibility, is inferior to the strength of the other Bessemer steel bars before experimented upon. Taking the average of all these latter bars, the mean value of C, the unit of working strength, is 5·8 tons; whereas this constant for the hæmatite bars is only 4·2 tons, showing that the former are about $\frac{1}{3}$ stronger than the latter. With about $\frac{1}{7}$ more weight laid on the bars their power of restitution was

measured by about $\frac{2}{3}$ of the whole deflection, showing that this load was considerably within that requisite to produce rupture. Owing to the high flexibility of the hæmatite bars, their modulus of elasticity is low. It may be here worthy of observation that, for bars of the same length, the modulus of elasticity varies inversely as the coefficient (D_1) of the deflection for unity of pressure and section, that is, $E \propto \frac{1}{D_1}$.

These bars underwent a great elongation by a tensile strain, and a large compression by a compressive strain, the average elongation being, per unit of length, .0792, and that of compression .419; whereas these numbers for the other bars, before experimented upon, did not, on an average, exceed .06 and .355 respectively, showing the flexibility and superiority of this steel in its powers to resist impact. The average tensile resistance of the bars is about 35 tons per square inch, whereas the resistance for the other Bessemer bars, before experimented upon, was about 42 tons; so that the tensile strength of the latter is $\frac{1}{3}$ greater than that of the former.

The quality of hardness of steel and wrought iron may be comparatively measured by the amount of extension under a given tensile strain, and the amount of compression under a given compressive strain. Applying this test to the results of the experiments on the various steel bars, we find that the hardest bars are the strongest, *irrespective of the companies by whom they were manufactured*. We find, for example, that the elongation per unit of length for eight of the best Bessemer bars did not exceed .018, and the compression per unit of length did not exceed .25. These bars had a temper probably exceeding that of spring-steel, and less than that for tools. The hæmatite bars are of a totally different description of steel from that manufactured for springs and tools, and this accounts for their comparatively low powers of resistance.

The experiments first made upon the hæmatite steel are anomalous. The first bar experimented upon showed great powers of resistance, but the last two gave results inferior to those obtained by the last experiments. At the same time the value (D_1) for unity of pressure and section, in the first experiments, is somewhat below the general average of the results of all the other experiments, thereby giving a considerable value to the modulus of elasticity. I suspect that the temper of the first bar was high; but whether the last two bars had a temper too high or too low, I am at a loss to determine. If it is desirable to have full justice done to the hæmatite steel bars as to their powers of resistance, a series of bars of the same degree of hardness as to the first bar mentioned, which gave considerably more than average powers of resistance, should be made, in order to compare with the harder descriptions of steel, as exhibited by other makers—numbers of which have, no doubt, been melted in the crucible, and selected for the purposes of experiment.

Abstract of the Experiments on the Heaton Steel.

This steel being the product of a totally different process of manufacture from that of all the other steel bars previously experimented upon, and as those bars were derived from the best known processes and received from the best of makers, it is a matter of the greater moment to ascertain how it stands in relation to them as regards strength and those other properties which are peculiar to steel. It is for this object that an abstract separate from that of the Barrow steel manufacture has been drawn up.

These bars, in their resistance to a transverse strain, show a very decided superiority over the steel bars which I experimented upon before, and on

which I reported to the British Association of 1867. For instance, the mean value of C , the unit of working strength for these bars, is 7·494 tons, whereas this value for the other bars was only 5·746 tons, showing that these bars are ·3 stronger. The value of u , or the work of deflection for unity of section, for these bars is 90·970, whereas for the other steel bars it is only 51·696. This value of u exhibits the powers of the several bars to resist a force analogous to that of impact. It is therefore clearly shown that this steel must be peculiarly well adapted to resist the force of sudden shocks, considering that it is $\frac{3}{4}$ superior in this quality to any other of the steel bars before experimented upon.

The flexibility of this steel is slightly inferior to that of other steel; the measure of flexibility (D_1) being for these bars ·001345, and for the other bars ·001361. The modulus of elasticity is somewhat low for steel, although at the same time it is very little below the general average of those from my former experiments.

This steel, I consider, well adapted to withstand severe transverse strains, for it combines the two essential qualities of great strength and superior powers in its resistance to the force of impact.

The mean breaking tensile strain, per square inch of section, of this steel is 45·28 tons; whereas this value for the other steel bars, before experimented upon, is 41·77 tons. The Heaton bars are, therefore, ·08 stronger in their resistance to the force of tension than the average result obtained from the steel bars previously experimented upon. This result, whilst placing the Heaton steel in a highly satisfactory position when compared with the mean of the whole of the steel experimented upon, places it at the same time below that produced by some individual manufacturers. The elongation of these bars was considerable, and a good deal above the mean for the other bars, thereby giving a large value for the work done in breaking the bar.

These bars show high powers of resistance to a compressive strain, all the specimens having undergone the test of 100 tons on the square inch without any visible external signs of fracture.

It would be very difficult to compare the different bars in their resistance to compression, for nearly all the specimens underwent a strain of above 100 tons on the square inch without exhibiting the slightest trace of a crack. As the lever by which the specimens were crushed was not competent to produce a greater strain, it was impossible to find out the crushing weight; besides, even then, supposing it possible to produce the requisite strain, it would be a task of extreme difficulty to find out at what precise weight the column began to give way. Under these circumstances, it can only be left to the judgment of the person wishing to select steel to resist a compressive force to choose that which he thinks best adapted to his purpose, the choice being regulated by the ductility of the metal as exhibited by the amount of compression. In looking through the experiments, however, one thing is clear, that the hardest steels sustained very little compression, whilst the softer ones, in the majority of cases, were reduced to almost half their original height.

From this abstract it will be seen that this steel, manufactured by Mr. Heaton, stands in the most favourable light in comparison with steel produced by other manufacturers; and if it be taken into consideration that two-thirds of the iron from which this steel was converted, was composed of Northamptonshire pig-iron, we may reasonably look forward to this invention creating a considerable improvement in the production and cost of steel.

Comparison of Wrought Iron with Steel.

Having lately had occasion to experiment on some wrought-iron bars, of

the best quality, used in the manufacture of armour-plates, by Messrs. J. Brown and Co., I avail myself of this opportunity of comparing the results obtained from this iron with those obtained from the steel bars. The wrought-iron bars were tested in exactly the same manner as the steel ones, and were successively subjected to transverse, tensile, and compressive strains; the results obtained from which will be found in the following abstract, where they are compared in their several strains to the steel bars.

The average value of C, the unit of working strength for wrought iron, is about 2.25 tons, whereas the value of this constant taken for fifteen of the best steel bars is 7.4 tons, so that the strength of the latter is $3\frac{3}{10}$ times that of the former. The average value, however, of C for the whole of the steel bars experimented upon is 5.921, showing that the average strength of steel in resisting a transverse strain is more than $2\frac{1}{2}$ times that of wrought iron. The mean transverse resistance per square inch for the wrought-iron bars, at the elastic limit, is equal to 6 C, or $6 \times 2\frac{1}{4}$, or $13\frac{1}{2}$ tons, which is somewhat greater than the resistance usually assigned to wrought-iron bars. The average value of D, for unity of pressure and section, for the wrought-iron bars is .00167, whereas the value of this constant for the steel bars is about .0013, showing that wrought-iron bars have a much greater flexibility than steel bars, and, as a necessary consequence, they have a much lower modulus of elasticity. Under a transverse strain the work of deflection up to the limit of elasticity is exceedingly low for wrought-iron bars; but the work expended in elongation up to the point of rupture is greater than the average of that determined for the steel bars: this is owing to the *extensibility* of the wrought iron; for whilst the unit of elongation for the average of the steel bars is not quite .05, that of wrought iron is .14, or about three times greater. The same observation applies to the work of compression. The average compression per unit of length is .45, whereas for the steel bars it is only about .3 of an inch.

The average breaking tensile strain, per square inch of section, of the wrought-iron bars is $25\frac{1}{4}$ tons, while this average for the steel bars is $42\frac{1}{2}$ tons, showing that the latter are $\frac{2}{3}$ stronger than the former. With a strain of $22\frac{1}{2}$ tons per square inch the wrought-iron bars had not entirely lost their powers of restitution, or the power of regaining, to some extent, the preceding set.

Although the short columns underwent a large compression under the action of a compressive force, yet the pressure corresponding to the first visible indication of rupture is considerable, being, on an average, about seventy tons per square inch, which is about two-thirds of that of hard steel columns. With comparatively soft material, like that of wrought iron, it is difficult to determine the exact point at which the material in such columns is fractured, so that the fullest reliance cannot be placed on the results of such experiments.

I have appended a general summary of all my experiments on steel, in order that comparisons may be readily made without the inconvenience of referring to the preceding Report. It may be stated that the experiments have given good results, and prove that steel can be produced of double the strength of wrought iron; and, at the same time, the homogeneity of its structure can be depended upon. If the cost of steel be reduced and approximates closer to that of iron, we may soon look forward for the substitution of this important metal in the place of iron.

GENERAL SUMMARY OF RESULTS.

TRANSVERSE STRAIN.

Manufacturer.	Mean value (D_1) of the deflection for unity of pressure and section.	Mean value of the modulus of elasticity (E).	Modulus of elasticity (E) corre- sponding to 112 lbs. pressure.	Work of deflection (U) up to the limit of elasticity.	Work of deflection (w) for unity of section.	Value of C , the unit of working strength.	Remarks.
Messrs. Naylor, Vickers, & Company ...	·0013007	30,278,000	29,481,000	66·660	65·049	tons, 6·548	Mean breaking-weight 1250 tons.
Messrs. S. Osborn & Company	·0014296	27,482,000	27,540,000	54·150	52·574	5·622	"
Messrs. C. Sanderson Brothers	·0013209	29,973,000	29,355,000	50·920	47·411	5·521	"
Messrs. T. Turton & Sons	·0013120	30,204,000	30,750,000	54·456	52·680	5·886	"
Messrs. J. Brown & Company	·0012739	30,370,000	31,551,000	51·038	52·721	5·918	"
Messrs. C. Cammell & Company	·0013518	29,166,000	30,696,000	65·059	59·897	5·921	"
Messrs. H. Bessemer & Company	·0016684	29,810,000	28,673,000	48·404	49·489	5·659	"
The Titanic Steel & Iron Company ...	·0012350	31,901,000	33,088,000	64·168	63·542	6·435	"
The Hematite Steel & Iron Company ...	·0013800	28,754,000	30,772,000	32·928	31·907	4·208	"
The Heaton Steel & Iron Company ...	·0013450	28,603,000	29,285,000	95·080	90·970	7·494	"
Mean	·0013611	29,663,000	30,118,000	58·286	56·624	5·921	

TENSILE STRAIN.

Manufacturer.	Specific gravity.	Weight laid on, producing rupture.	Breaking-strain per square inch of section.	Elongation per unit of length.	Value of u , or work producing rupture.
Messrs. Naylor, Vickers, & Company.....	7·8198	lbs. 39449	lbs. 108099	tons. 48·25	1827
Messrs. S. Osborn & Company	7·7758	44131	103214	46·07	1842
Messrs. C. Sanderson Brothers	7·7563	39592	95553	42·65	1566
Messrs. T. Turton & Sons	7·7990	39295	93380	41·61	807
Messrs. J. Brown & Company	7·7665	33603	90379	40·35	2002
Messrs. C. Cammell & Company	7·8119	34085	103132	45·14	2714
Messrs. H. Bessemer & Company	7·7726	38189	89955	40·16	3212
The Titanic Steel & Iron Company	7·7883	37179	93616	41·79	2413
The Haematite Steel & Iron Company	7·7744	33527	76550	34·17	2949
The Heaton Steel & Iron Company	7·8142	44943	101513	45·28	3414
Mean	7·7878	38399	95339	42·54	2274

COMPRESSION.

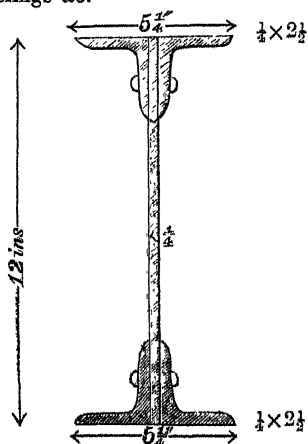
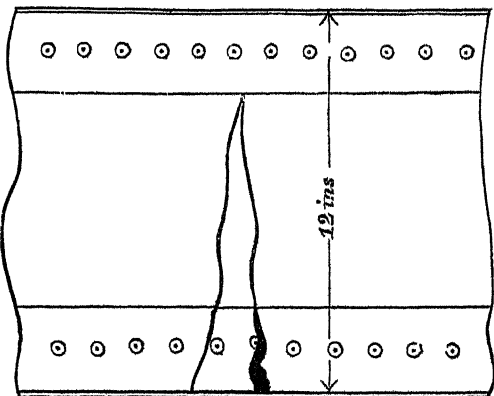
Manufacturer.	Weight laid on.	Greatest weight laid on per square inch of section.	Compression, per unit of length.	Value of u , or work expended in crushing the bar.
Messrs. Naylor, Vickers, & Company.....	lbs. 91840	lbs. 225568	tons. 100·700	32300
Messrs. S. Osborn & Company	91840	225568	100·700	30014
Messrs. C. Sanderson Brothers	91840	225568	100·700	36006
Messrs. T. Turton & Sons	91840	225568	100·700	44888
Messrs. J. Brown & Company	91840	225568	100·700	39136
Messrs. C. Cammell & Company	91840	225568	100·700	38233
Messrs. H. Bessemer & Company	91840	225568	100·700	42720
The Titanic Steel & Iron Company	91840	225568	100·700	35551
The Haematite Steel & Iron Company	91840	225568	100·700	45813
The Heaton Steel & Iron Company	91840	225568	100·700	31391
Mean	91840	225568	100·700	37695

APPENDIX I.

In addition to the foregoing experiments, it was considered desirable to have a steel beam made of the usual form, in order to ascertain the comparative merits of steel and wrought-iron girders. For this purpose two beams were constructed, of that quality of steel best suited to ensure durability and safety. A much harder description of steel (40 tons to the square inch) might have been chosen; but that was not wanted, for the object sought was ductility and moderate strength in its powers to resist impact. The following experiments will show the results.

Experiment on a Steel Girder from the Barrow Hæmatite Steel Company.

Length between the supports 13·9 feet. Sectional area 2·31 inches.

No. of Expt.	Weight laid on girder.		Deflection, in inches.	Remarks.
	lbs.	tons.		
1	866	0·386	...	Weight of slings &c.
2	3106	1·386	·056	
3	5346	2·386	·108	
4	7586	3·386	·147	
5	9826	4·386	·184	
6	12068	5·386	·201	
7	14308	6·386	·260	
8	16550	7·386	·304	
9	18790	8·386	·322	
10	21020	9·386	·339	
11	23260	10·386	·372	
12	26880	12·000	·423	
13	29120	13·000	·480	
14	33600	15·000	·545	
15	35840	16·000	·626	
16	36060	16·098	·802	
17	38080	17·000	·965	
18	39200	17·500	1·430	
19	40320	18·000	1·872	
20	40544	18·100	...	Broke by tension through the angle-iron of the bottom flange, as above.

A wrought-iron girder of the same dimensions would break with 11·8 tons. The comparison, therefore, stands as 18·1:11·8, being in the ratio of 1:·652. The resistance of this description of steel to a transverse strain is therefore more than one and a half times greater than that of wrought iron.

Experiment on a Steel Girder from the Barrow Hæmatite Steel Company (April 1868).

Length between supports 13·9 feet. Sectional area 2·31 inches.

No. of Exp.	Weight laid on girder.		Deflection, in inches.	Remarks.
	lbs.	tons.		
1	12152	5·425	·196	This weight remained on 120 hours.
2	18872	8·425	·330	
3	24192	10·800	·442	
4	29512	13·175	·524	This last weight having remained upon the beam a short time, it suddenly gave way by lateral flexure, and one of the angle-irons being broken, the experiment was discontinued.

There is great difficulty in testing beams of this description, arising from the narrow top and bottom flanges, which, to prevent injury from lateral flexure, should be loaded and broken through the sides of a rigid frame. In this case the beam was identical in every respect with the previous one, and would have carried the same weight but for the lateral injuries it received in the early stages of the experiment. Taking, however, the strength of steel beams and the amount of deflection when submitted to a transverse strain, it will be found that they are not only one-third stronger than those of the best wrought iron, but they are much superior in their powers to resist impact, and therefore more secure under the influence of a rolling load or severe vibratory action often repeated.

Taking into account the peculiar properties of this material, its superior strength, the saving of one-third in weight, and other conditions of security, it is (under the conditions of perfect uniformity of character in the manufacture) admirably adapted for rolled joists and girders, as also for bridges, where high powers of strength and elasticity are required to resist the united forces of load and impact.

APPENDIX II.

The 'Practical Mechanics' Journal' gives the following description of the furnace and apparatus for the manufacture of steel on the Heaton system. See Plate II. :—

The Heaton converter (fig. A) is nearly a cylindrical cupola, lined with 4½-inch fire-brick, the shell of boiler plate, and surmounted by a plate-iron conical cap and narrower cylindrical flue of a few feet in height. The cupola may be supposed cut in two horizontally at about one diameter and a half in height,

and the bottom part rendered moveable and capable of being withdrawn on wheels, without disturbance to the supports &c. of the remaining upper portion of the converter. Ready means of temporary attachment by clamps and cotters are provided to connect the two parts, which thus so far present a close resemblance to the *Calebasse* cupola still in use in Belgium. At one side of the cylindric fixed part of the converter, a sort of hopper, with a loosely hinged iron-plate cover, is provided, which communicates with the cavity within.

"The lower part, or "converting-pot," has a cylindrical cavity with a flat bottom, and with the sides near the top edge sloping inwards to a cone all round. The cavity, up to the level of the lower edge of this cone, is prepared to just hold the bulk of crude nitrate of soda required for the volume of liquid iron to be operated on, and for the latter when converted; the proportion of nitrate, as at present employed by the patentee, being 2 cwt. to the ton of liquid iron, or 10 per cent.—a proportion, we may remark, which both the metallurgists who have been engaged in examining this process by the present owners of the patents are of opinion is a good deal in excess of what is needed, when the conditions for the most favourable reaction shall be more completely and more scientifically understood. The "converting-pot" is lined with fire-brick and refractory clay. When the crude nitrate is filled in and levelled up to, or a trifle beyond, the narrow part of the conical lining, the cast-iron perforated plate is simply laid upon its level surface, and worked round a little until its edges bed firmly into and upon the clay lining. In this state the converting-pot is rolled in under the upper part of the converter, clamped up to it, and the whole is now ready for work.

"The charge of crude cast iron is melted with coke in an ordinary cupola; at present it is tapped out into a crane-ladle. This is swung round by the crane, and the contents at once emptied into the opened hopper of the converter. The molten iron falls upon the cold cast-iron plate; its lowermost stratum is for the moment chilled and nearly consolidated by the heat withdrawn by contact, and for some minutes there is no perceptible action. In this state a vertical section of the charged and filled converter is represented by fig. 1. Soon, however, the lower stratum recovers its liquidity, and begins to penetrate below the now more than red-hot and softened perforated cast-iron plate, and reaction commences, evidenced by the appearance of white and grey vapours at the top of the converter-funnel. The nitrate has no doubt by this time got much impacted and partly fused at its upper strata. The reaction producing a large accession of heat at the plane of contact of the molten iron and of nitrate, the plate melts and disappears. A burst of brilliant yellow flame at the top of the converter-funnel indicates that the reaction is then at its height. This lasts steadily for some few minutes (three to five usually, with 12 or 15 cwt. charges), and then rapidly subsides. The conversion is now complete. The bottom of the converter, or "converting-pot," is now detached and rolled away, and the converter is ready for another bottom and another charge.

"When we examine the converting-pot withdrawn, we find its surface covered to the depth of an inch or two with a dark "blabby slag," through which brilliant jets of yellow sodium-coloured flame from escaping gases are constantly spouting. This slag consists chiefly of the soda of the nitrate, combined with silica and clayey matters derived from the lining of the converter, and involving some "shots" of metallic iron or steel, and some little silicate of iron, &c. Beneath this is the converted metal, which the patentee calls "crude steel." It forms a white-hot, *boursoufflée*, and tolerably liquid



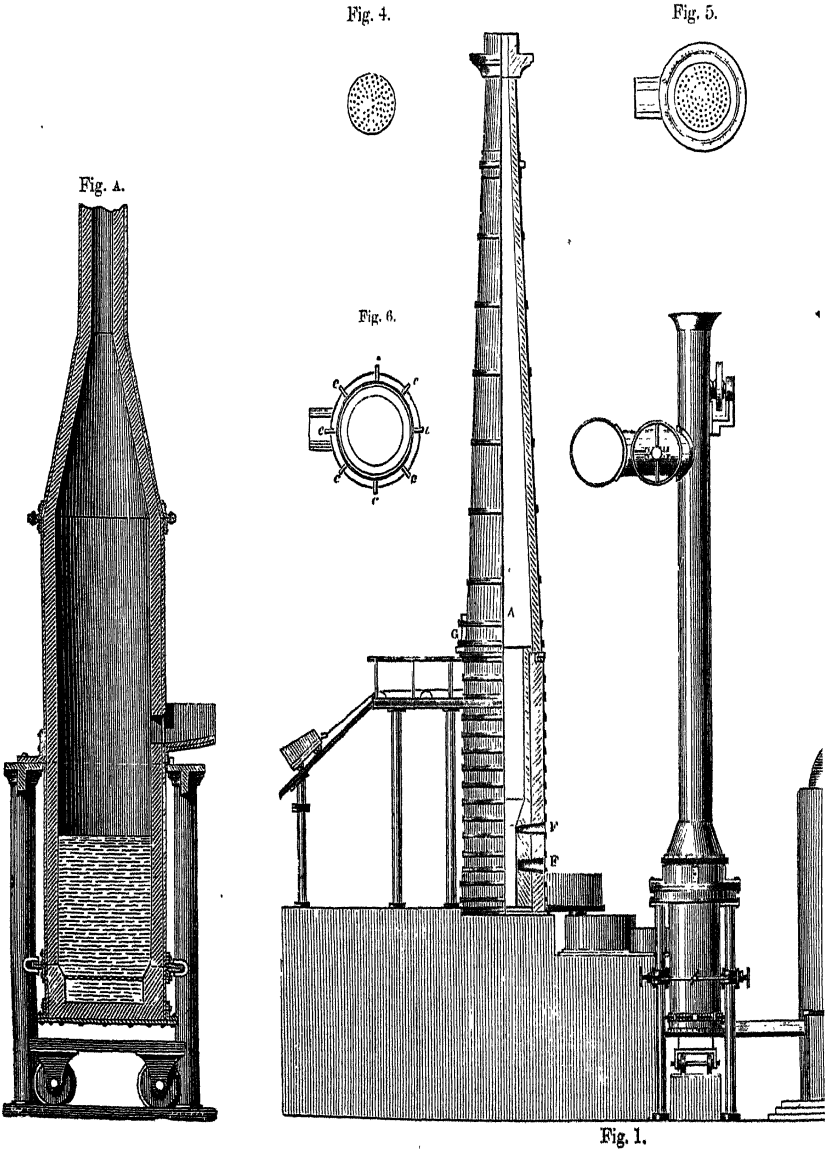


Fig. 3.

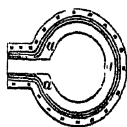
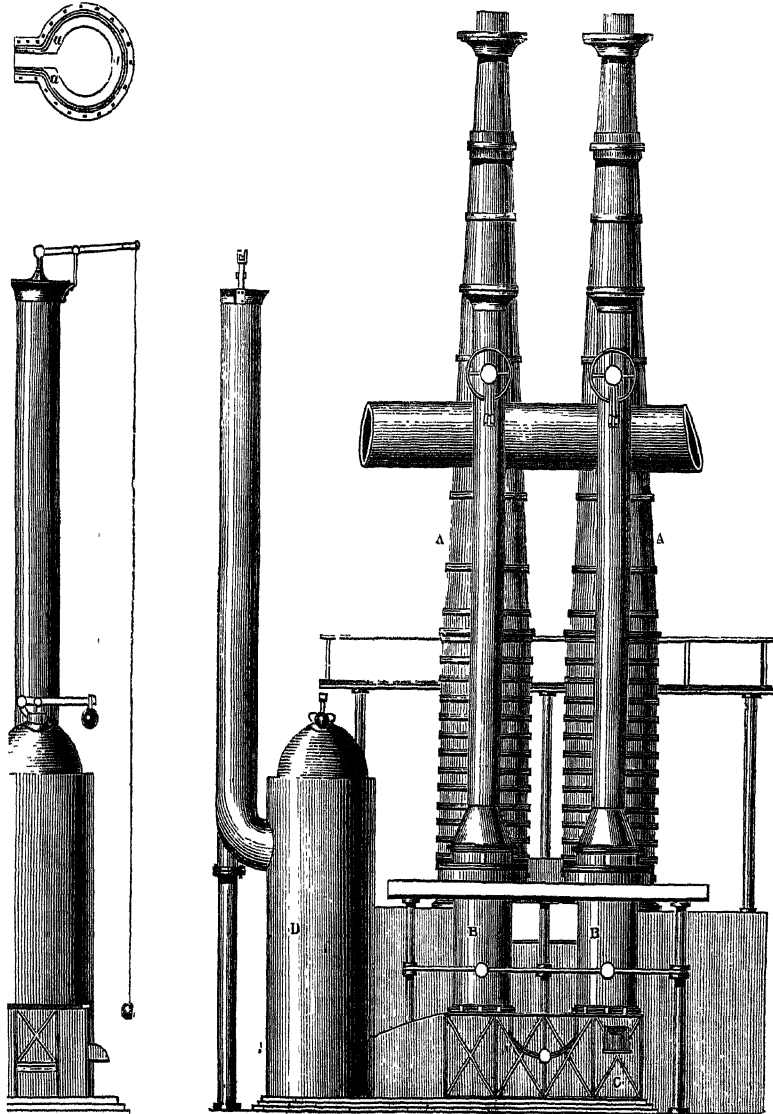


Fig. 2.



the pig, but allowing for the waste upon it at the ratio of 60 lbs. per ton, is £2 4s. per ton, or £2 15s. in crude steel cakes; the cost of making it into "steel-iron" bars, from the pig-iron, is £3 10s. per ton for finished bars, and the cost of making tilted cast-steel bars, from the pig-iron, is £12 15s. per ton. We have seen the invoices of cast-steel bars of this sort, sold from Langley Mills, at prices equal to those now current at Sheffield for well-reputed cast steel made by the process of cementation."

Second Report on the British Fossil Corals.

By DR. P. MARTIN DUNCAN, F.R.S., F. & Sec. Geol. Soc.

THIS Report comprehends the description of the Coral-fauna of the periods when the strata of the Gault, Lower Greensand, Portland Oolite, Coral Rag, Great Oolite, and Inferior Oolite were deposited. It contains a general view of the physico-geographical conditions of the British area during the Tertiary and Secondary periods so far as relates to coral growth, and also an enumeration and a list of the species.

The result of the labour entailed by the study of the Tertiary and Secondary British Fossil corals has been to add 146 species and many varieties to the 111 or 112 previously known.

Since the last Report was read, the fossil Corals of the Upper and Lower Red Chalk and of the Upper Greensand have been published in my monograph for the Palæontographical Society.

Much progress has been made in the Report on the Palæozoic Corals, but the Report itself cannot be completed for some time.

Corals from the Gault.

Only six well-marked species of corals were known to MM. Milne-Edwards and Jules Haime as having been found in the Gault. They were all simple or solitary forms, and such as one would expect to find in moderately deep water. It is evident that the area occupied by the English Gault was not the coral tract of the period. The resemblance of the coral-faunas of the Gault and the London Clay is somewhat remarkable, and probably the physical conditions of the areas during the deposition of the strata were not very dissimilar,

MADREPORARIA APOROSA.

Family TURBINOLIDÆ.

Subfamily CARYOPHYLLINÆ.

Division CARYOPHYLLACEÆ.

Genus CARYOPHYLLIA.

MM. Milne-Edwards and Jules Haime have changed the generic term *Cyathina* into that of its predecessor *Caryophyllia*; consequently *Cyathina Bowerbanki*, Ed. & H., is now called *Caryophyllia Bowerbanki*, Ed. & H. (Hist. Nat. des Corall. vol. ii. p. 18).

A very interesting variety of this species is in the Rev. T. Wiltshire's Collection, and has its costæ running obliquely to the long axis of the corallum. They are profusely granulated.

Division TROCHOCYATHACEÆ.

Genus TROCHOCYATHUS.

1. *Trochocyathus Harveyanus*, Ed. & H.

This species was described by MM. Milne-Edwards and Jules Haime in their 'Monograph of the British Fossil Corals,' part 1. p. 65. They associated it with two species, which are, as they suggest, undistinguishable, viz. *Trochocyathus Konigi* and *Trochocyathus Warburtoni*. The first of these species is the *Turbinolia Konigi* of Mantell.

An examination of a series of specimens attributed to *Trochocyathus Harveyanus*, Ed. & H., and the consideration of the value of the *Trochocyathi* just mentioned, have led me to recognize five forms of *Trochocyathi breves*, all closely allied and well represented by the original type of *Trochocyathus Harveyanus*, Ed. & H. When placed in a series with this *Trochocyathus* at the head, there is a gradation of structure which prevents a strictly specific distinction being made between the consecutive forms; but when the first and the last forms are compared alone, no one would hesitate to assert that there is a specific distinction between them. All the forms are simple, short, and almost hemispherical; all have four cycles of septa and the same proportion of pali. These are the primary and most essential peculiarities of the genus.

The costæ differ in their size, prominence, ornamentation, and relation to the septa in some of the forms; and the exsert nature of the septa, their granulation, and the size of the corallum also differ. The structural differences are seen in many examples, and are therefore more or less persistent; nevertheless it is found that whilst several specimens have the septa springing from intercostal spaces instead of from the ends of the costæ, one or more, having all the other common structural peculiarities, present septa arising from the costal ends. This method of origin can hardly constitute a specific distinction. I propose to retain *Trochocyathus Harveyanus* as the type of a series of forms, the sum of whose variations in structure constitutes the species.

Variety 1. The corallum is nearly double the size of the type; its septa are rather exsert, and are very granular. The costæ are very prominent, ridged, marked with numerous small pits, and are continuous with the septa. The epitheca is waved and well developed. The spaces between the larger costæ are more or less angular. The peduncle is large.

Locality. Gault, Folkestone. In the British Museum.

Variety 2. The corallum is as large as that of *variety 1*, but it is more conical. The costæ are less pronounced, and the septa, which are more granular than those of *variety 1*, arise from the intercostal spaces. The costal ends are very elegant in shape, and form a margin of rather sharp curves.

Locality. Gault, Folkestone. In the British Museum.

Variety 3. The corallum is rather flat, but hemispherical. The septa are not exsert, and they arise from the costal ends. The costæ are equal: none are more prominent than others. They are all rather broad, flat, and beautifully ornamented with diverging curved lines. Their free ends are equal and curved.

Locality. Gault, Folkestone. In the collection of the Rev. T. Wiltshire, F.G.S.

Variety 4. The corallum and costæ are like *variety 3*, but the septa arise from the intercostal spaces.

Locality. Gault, Folkestone.

In the collection of the Rev. T. Wiltshire, F.G.S.

Variety 5. The corallum is rather more conical inferiorly than in *varieties 3 and 4*. The septa are exsert, and project slightly beyond the costal margin. The costæ are all rudimentary. The epitheca is well developed, and reaches up to the septa.

Locality. Gault, Folkestone.

The forms may be distinguished as follows:—

With more or less ridged costæ	{ The type. Variety 1. " 2.
With nearly equal flat costæ	{ Variety 3. " 4.
Costæ rudimentary	" 5.
Septa arising from the costal ends	{ The type. Variety 1. " 3.
Septa arising from the intercostal spaces	{ Variety 2. " 4.

All the forms have four cycles of septa and pali before the first, second, and third orders.

2. *Trochocyathus Wiltshirei*, Duncan.

The corallum is straight, conical, and either cylindrical above or compressed; its base presents the trace of a peduncle for attachment. The epitheca is scanty and in transverse masses. The costæ are distinct and subequal. The calice is very open and rather deep. The septa are unequal, hardly exsert, and broad at the margin of the calice. There are four cycles of septa, and six systems. The pali are large, and are placed before all the cycles except the last. The columella is rudimentary.

Height $\frac{3}{10}$ inch. Breadth of calice $\frac{3}{10}$ inch.

Locality. Gault, Folkestone. In the zone of *Ammonites dentatus*.

In the Royal School of Mines, and in the collection of the Rev. T. Wiltshire, F.G.S.

This species is closely allied to *Trochocyathus conulus*, Phillips, sp. The compressed calice, the rudimentary columella, and the shape of the corallum distinguish the new species from *Trochocyathus conulus*.

Genus LEPTOCYATHUS.

Leptocyathus gracilis, Duncan.

The corallum is small, flat, and circular in outline. The costæ are very prominent, and join exsert septa; the primary and secondary costæ are very distinct, and the others less so. All the costæ unite centrally at the base; many are slightly curved. The septa are thick externally, very unequal, thin internally, and the largest are more exsert than the others. There are six systems and four cycles of septa. The pali are small and exist before all the septa. The columella is very rudimentary. The calicular fossa is rather wide and shallow.

Height hardly $\frac{1}{10}$ inch. Breadth $\frac{3}{10}$ inch.

Locality. Gault, Folkestone.

In the British Museum.

This species is very closely allied to *Leptocyathus elegans*, Ed. & H., of the London Clay. *Leptocyathus elegans* has not a flat base, and it has very granular septa. Moreover, its costæ are large and small in sets. Nevertheless the alliance is of the closest kind.

Genus BATHYCYATHUS.

MM. Milne-Edwards and Jules Haime described a species of this genus in their 'Monograph of the British Fossil Corals,' pt. 1. pp. 67, 68. Two specimens in the collection of the Rev. T. Wiltshire present all the appearances recognized by those distinguished authors. The costæ are very granular, and not in a simple row. In one specimen the breadth of the base is very great.

Subfamily TURBINOLINÆ.

Division TURBINOLIACEÆ.

Genus SMILOTROCHUS.

Some species of this genus were described amongst the corals from the Upper Greensand, and one was noticed as belonging to this geological horizon which should have been included in the Lower Greensand forms.

The Upper Greensand *Smilotrochi* are:—

Smilotrochus tuberosus, Ed. & H.

Smilotrochus angulatus, Duncan.

— *elongatus*, Duncan.

There are four species of the genus found in the Gault, which are all closely allied; one of them cannot be distinguished from *Smilotrochus elongatus* of the Upper Greensand.

The specimens of this species found in the Upper Greensand are invariably worn and rolled, and are generally in the form of casts; but in the Gault the structural details are well preserved, and even the lateral spines on the septa are distinct.

The Gault forms are shorter and more cylindro-conical and curved than those from the Upper Greensand.

The species of the genus *Smilotrochus* from the Gault are as follows:—

1. *Smilotrochus elongatus*, Duncan.

3. *Smilotrochus granulatus*, Duncan.

2. — *cylindricus*, Duncan.

4. — *insignis*, Duncan.

1. *Smilotrochus elongatus*, Duncan.

This species was described in the first Report.

Locality. Folkestone.

In the collection of the Royal School of Mines.

The lateral spines of the septa are very well marked, and the costæ are equal in size in this species. Its septal number varies, on account of the very late perfection of the fourth cycle of septa.

2. *Smilotrochus cylindricus*, Duncan.

The corallum is small, cylindrical, nearly straight, and has a truncated base. The costæ are equal, very distinct above, and rudimentary below and in the middle; they are marked with a few large granules in one series. The septa are subequal, very exsert, thin, close, and marked with large granules, few in number. The septa are in six systems, and there are three cycles.

Height $\frac{3}{10}$ inch. Greatest breadth rather less than $\frac{2}{10}$ inch.

Locality. Gault, Folkestone.

In the collection of the Rev. T. Wiltshire, F.G.S.

3. *Smilotrochus granulatus*, Duncan.

The corallum is conico-cylindrical in shape, and has a more or less truncated base. The costæ are subequal, prominent, very granular, and distinct superiorly. The septa are subequal, thick, and very granular. The septa are in six systems, and there are three cycles.

Height $\frac{9}{10}$ inch. Breadth $\frac{3}{10}$ inch.

Locality. Gault, Folkestone.

In the collection of the Rev. T. Wiltshire, F.G.S.

4. *Smilotrochus insignis*, Duncan.

The corallum is trochoid, short, has a wide calice and a conical and rounded base; the calice is circular in outline, the fossa is deep and small, and the septa are wide, exsert, curved above, and so marked with one row of granules that their free margin appears to be spined. There are three cycles of septa, and the orders are nearly equal as regards size. The costæ are large, prominent, broad at their base, and are marked with one row of granules on the free surface.

Height $\frac{2}{10}$ inch. Breadth of calice $\frac{2}{10}$ inch.

Locality. Gault, Folkestone.

In the collection of the Rev. T. Wiltshire, F.G.S.

An analysis of the genus will be found after the description of the species from the Lower Greensand.

There is a compound or aggregate Madreporarian found in the Gault of Folkestone. It has much endotheca, and resembles worn specimens of the well-known *Holocystis elegans* of the Lower Greensand. The specimens are not sufficiently well preserved for identification with any genus.

Family FUNGIDÆ.

Subfamily FUNGINÆ.

Genus MICRABACIA.

Micrabacia Fittoni, Duncan.

The corallum is nearly hemispherical in shape; its base is flat and extends beyond the origin of the septa in a sharp and uninverted margin. The breadth of the base exceeds the height of the corallum. The costæ are flat, straight, convex externally at the calicular margin, and equal. The septa are unequal, much smaller than the costæ. There are four cycles of septa, in six systems; the synapticalæ between the septa are large.

Height $\frac{2}{10}$ in. Breadth nearly $\frac{1}{2}$ inch.

Locality. Gault, Folkestone.

In the collection of the Rev. T. Wiltshire, F.G.S.

The flat base, the flat costæ, and the limitation of the septal number to four cycles distinguish this species from *Micrabacia coronula** of the Upper Greensand, and from *Micrabacia Beaumontii*†, Ed. & H., of the Neocomian.

List of new Species from the Gault.

Variety of *Caryophyllia Bowerbanki*, Ed.

& H.

Five varieties of *Trochocyathus Harveyanus*,

Ed. & H.

Trochocyathus Wiltshiri, Duncan.

Leptocyathus gracilis, Duncan.

Smilotrochus elongatus, Duncan.

— *granulatus*, Duncan.

— *insignis*, Duncan.

— *cylindricus*, Duncan.

Micrabacia Fittoni, Duncan.

* Hist. Nat. des Coral. vol. iii. p. 30.

† Ibid. p. 30.

List of species from the Gault.*

- | | |
|--|--|
| 1. Caryophyllia Bowerbanki, <i>Ed. & H.</i> , and one variety. | 7. Cyclocyathus Fittoni, <i>Ed. & H.</i> |
| 2. Trochocyathus conulus, <i>Phillips</i> , sp. | 8. Smilotrochus elongatus, <i>Duncan</i> †. |
| 3. — Wiltshiri, <i>Duncan</i> . | 9. — granulatus, <i>Duncan</i> . |
| 4. — Harveyanus, <i>Ed. & H.</i> , and five varieties. | 10. — cylindricus, <i>Duncan</i> . |
| 5. Bathycyathus Sowerbyi, <i>Ed. & H.</i> | 11. — insignis, <i>Duncan</i> . |
| 6. Leptocyathus gracilis, <i>Duncan</i> . | 12. Trochosmia sulcata, <i>Ed. & H.</i> |
| | 13. Micrabacia Fittoni, <i>Duncan</i> . |

Corals from the Lower Greensand.

One species of Coral was described by MM. Milne-Edwards and Jules Haime from the Lower Greensand, in their 'Monograph of the British Fossil Corals.'

Fitton had noticed a compound coral in the Lower Greensand, and named it *Astræa* in his "Essay on the Strata below the Chalk," Geol. Trans. 2nd series, vol. iv. p. 352 (1843). In 1847 he called the species *Astræa elegans*; and Lonsdale separated it from the *Astræidæ* under the name *Cyathophora elegans* in 1849 (Proceed. Geol. Soc. vol. v. pt. 1, p. 83, tab. iv. figs. 12, 15: 1849).

MM. Milne-Edwards and Jules Haime recognized the quadrate arrangement of the septa of this species, and classified it amongst the *Rugosa*, in the family *Stauridæ*. Their *Holocystis elegans*, Fitton, sp., is a very good species, and specimens are found varying in the size of the corallum and of the calices.

Since the publication of their 'Monograph on the British Corals,' MM. Milne-Edwards and Jules Haime have named a species from Farrington *Smilotrochus Austeni* (Hist. Nat. des Corall. vol. ii. p. 71). I have noticed it inadvertently in my description of the Upper Greensand Corals. In order to complete this part it is introduced here again.

Family TURBINOLIDÆ.

Division TURBINOLIACEÆ.

Genus SMILOTROCHUS.

Smilotrochus Austeni, *Ed. & H.*

The corallum is regularly cuneiform, very much compressed below, and slightly elongate. The calice is elliptical; the summit of the larger axis is rounded. Forty-eight costæ, subequal, straight, fine and granular.

Height of the corallum about $\frac{1}{3}$ inch.

Locality. Farrington.

MM. Milne-Edwards and Jules Haime do not mention where the specimen is deposited.

The genus *Smilotrochus* has become of some importance in the palæonto-

* The following authors have written upon the fossil Corals of the Gault:—MM. Milne-Edwards and Jules Haime, 'Monograph of the British Fossil Corals' (Pal. Soc.); 'Hist. Nat. des Coralliaires.' Phillips, 'Illust. of Geol. of Yorkshire.' Mantell, 'Geol. of Sussex.' Lonsdale in Fleming's, 'British Animals.'

The authors who have written upon the Corals of the Lower Greensand are:—MM. Milne-Edwards and Jules Haime, *op. cit.* Fitton, 'Quart. Journ. Geol. Soc.' vol. iii. p. 296 (1847). Lonsdale, 'Proc. Geol. Soc.' vol. v. pt. 1. p. 83. M. de Fromental has paid especial attention to the French Neocomian corals, and C. J. Meyer, Esq., has enabled me to study the most interesting species in his collection.

† Common to the Gault and Upper Greensand.

logy of the Cretaceous rocks. The species are distributed as follows in Great Britain:—

<i>Smilotrochus tuberosus</i> , Ed. & H.	} Upper Greensand.
— <i>elongatus</i> , Duncan.	
— <i>angulatus</i> , Duncan.	
— <i>elongatus</i> , Duncan.	} Gault.
— <i>granulatus</i> , Duncan.	
— <i>insignis</i> , Duncan.	
— <i>cylindricus</i> , Duncan.	
— <i>Austeni</i> , Ed. & H.	Lower Greensand.

Smilotrochus elongatus, Duncan, is found in the Gault and Upper Greensand.

Smilotrochus Hagenowi, Ed. & H., is a fossil from the Maestricht Chalk (Ed. & H. Hist. Nat. des Corall. vol. ii. p. 71).

Subfamily CARYOPHYLLINÆ.

Division CARYOPHYLLIACEÆ.

Genus BRACHYCYATHUS.

Brachycyathus Orbignyianus, Ed. & H.

The corallum is very short. The costæ are indistinct. The septa are long, very slightly exsert, granulated from below upwards, and there are four cycles in six systems. The primary and secondary septa are equal; the tertiary are a little longer than those of the fourth cycle; all are thin and straight. The pali are like continuations of the tertiary septa before which they are placed; they are granular.

Height $\frac{1}{10}$ inch. Breadth $\frac{6}{10}$ inch.

Locality. East Shalford, Surrey, base of the Lower Greensand. Found with *Cerithium Neocomiense*, D'Orbig.; *Exogyra subplicata*, Tqm.; *Arca Raulina*, Leym.; *Terebratula sella*, Sow.

In the collection of C. J. Meyer, Esq., F.G.S.

The specimen upon which the genus was founded was found in the Neocomian formation of the Hautes Alpes, at St. Julien, Beauchêne. I have added to the original description, as some portions of the English specimen are better preserved than the type.

Family ASTRÆIDÆ.

Subfamily EUSMILINÆ.

Division TROCHOSMILIACEÆ.

Genus TROCHOSMILIA.

Trochosmilia Meyeri, Duncan.

The corallum is small, cylindrical or cylindro-conical; its base may be wide or very small, and was adherent. The epitheca is complete. The costæ are very small, and are occasionally seen where the epitheca is worn. The calice is rather deep. The septa are crowded, unequal, spined near the axis, and form six systems. There are four cycles of septa. The calice is usually circular in outline, but it is occasionally compressed. The axial space is small. The endothea is very scanty.

Height $\frac{4}{10}$ inch. Greatest breadth $\frac{2}{10}$ inch.

Variety. The corallum is short, broad, cylindrical, slightly constricted centrally, and has a broad base.

Height $\frac{3}{10}$ inch. Breadth $\frac{8}{10}$ inch.

Locality. Bargate Stone, upper division of the Lower Greensand, Guildford, Surrey. Found with "*Avicula pectinata*," Sow.

In the collection of C. J. Meyer, Esq., F.G.S.

The small *Trochosmilæ* are common in the Bargate Stone, where they were discovered by Mr. Meyer, from whom I have obtained the names of the associated fossils. The presence of epitheca would apparently necessitate these fossils being placed in a new genus; but after a careful examination of the bearings of the absence or presence of the epithecal structures upon the natural classification of simple corals, I do not think the point sufficiently important to bring about the separation of Mr. Meyer's little corals from the *Trochosmilæ*; they form (*i. e.* the type and variety) a subgenus of the *Trochosmilæ*.

Subfamily ASTRÆINÆ.

Division ASTRÆACEÆ.

Genus ISASTRÆA.

Isastræa Morrisi, Duncan.

The corallum is flat and very short. The corallites are unequal and usually five-sided. There is no columella. The wall is thin. The septa are slender, unequal, and most of them reach far inwards. There are in the perfect calices three cycles of septa in six systems; usually some of the septa of the third cycle are wanting.

Breadth of a calice rather more than $1\frac{1}{10}$ inch.

Locality. Bargate Stone, Guildford, Surrey; with *Terebratella Fittoni*, Meyer.

In the collection of C. J. Meyer, Esq., F.G.S.

This small *Isastræa* is usually found as a cast, and the restored drawing is taken from an impression. The central circular structure is due to fossilization.

The species is closely allied to *Isastræa Guettardana*, Ed. & H., of the Lower Chalk of Uchaux.

Family FUNGIDÆ.

Subfamily LOPHOSERINÆ.

Genus TURBINOSERIS, gen. nov.

The corallum is simple, more or less turbinate or constricted midway between the base and calice; the base is either broad and adherent, or small and free.

There is no epitheca, and the costæ are distinct. There is no columella, and the septa unite laterally, and are very numerous.

Turbinoseris de-Fromenteli, Duncan.

The corallum is tall, and more or less cylindro-turbinate. The calice is shallow, and circular in outline. The septa are very numerous, long, thin, straight, and many unite laterally with longer ones. There are 120 septa, and the cyclical arrangement is confused. The synapticulæ are well developed. There is no columella, and the longest septa reach across the axial space. The costæ are well developed, and often are not continuous with the septal ends.

Height $1\frac{3}{10}$ inch. Breadth of calice $1\frac{2}{10}$ inch.

Variety. With a constricted wall and large base.

Locality. Atherfield, in the Lower Greensand.

In the collection of the Royal School of Mines.

The necessity for forming a new genus for this species is obvious; it is

the neighbour of *Trochoseris* in the subfamily of the *Lophoserinæ*. This last genus has a columella, and the new one has none.

The species has not been hitherto described, but it has been familiarly known as a *Montlivaltia*; but the synapticulæ between the septa and costæ determine the form to belong to the *Fungidae*.

List of new Species from the Lower Greensand.

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| 1. <i>Brachycyathus Orbignyanus</i> , Ed. & H. | 3. <i>Isastræa Morrisi</i> , Duncan. |
| 2. <i>Trochosmilium Meyeri</i> , Duncan. | 4. <i>Turbinoseris de-Fromenteli</i> , Duncan. |

List of the Species from the Lower Greensand.

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| 1. <i>Brachycyathus Orbignyanus</i> , Ed. & H. | 4. <i>Isastræa Morrisi</i> , Duncan. |
| 2. <i>Smilitrochus Austeni</i> , Ed. & H. | 5. <i>Turbinoseris de-Fromenteli</i> , Duncan. |
| 3. <i>Trochosmilium Meyeri</i> , Duncan. | 6. <i>Holocystis elegans</i> , Lonsdale, sp. |

List of the Species from the Cretaceous Formations.

a. Upper and Lower White Chalk.

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| 1. <i>Caryophyllia cylindracea</i> , Reuss, sp. | 11. <i>Parasmilia centralis</i> , Mantell, sp., and two varieties. |
| 2. ——— <i>Lonsdalei</i> , Duncan. | 12. ——— <i>cylindrica</i> , Ed. & H. |
| 3. ——— <i>Tennanti</i> , Duncan. | 13. ——— <i>Fittoni</i> , Ed. & H. |
| 4. <i>Onchotrochus serpentinus</i> , Duncan. | 14. ——— <i>serpentina</i> , Ed. & H. |
| 5. <i>Trochosmilium laxa</i> , Ed. & H., sp., and three varieties. | 15. ——— <i>monilis</i> , Duncan. |
| 6. ——— <i>cornucopiæ</i> , Duncan. | 16. ——— <i>granulata</i> , Duncan. |
| 7. ——— <i>Wiltshiri</i> , Duncan. | 17. <i>Diblasus Gravensis</i> , Lonsdale. |
| 8. ——— <i>Woodwardi</i> , Duncan. | 18. <i>Synhelia Sharpeana</i> , Ed. & H. |
| 9. ——— <i>granulata</i> , Duncan. | 19. <i>Stephanophyllia Bowerbanki</i> , Ed. & H. |
| 10. ——— <i>cylindracea</i> , Duncan. | |

b. Upper Greensand.

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| 20. <i>Onchotrochus Carteri</i> , Duncan. | 28.* <i>Placosmilium magnifica</i> , Duncan. |
| 21. <i>Smilitrochus tuberosus</i> , Ed. & H. | 29.* <i>Astrocenia decaphylla</i> , Ed. & H. |
| 22. ——— <i>elongatus</i> , Duncan. | 30.* <i>Isastræa Haldonensis</i> , Duncan. |
| 23. ——— <i>angulatus</i> , Duncan. | 31. <i>Cyathophora monticularia</i> , D'Orbigny. |
| 24. <i>Peplosmilium Austeni</i> , Ed. & H. | 32. <i>Favia stricta</i> , Ed. & H. |
| 25.* ——— <i>depressa</i> , E. de From. | 33. ——— <i>minutissima</i> , Duncan. |
| 26.* <i>Placosmilium cuneiformis</i> , Ed. & H. | 34. <i>Thamnastræa superposita</i> , Michelin. |
| 27.* ——— <i>Parkinsoni</i> , Ed. & H. | 35. <i>Micrabacia coronula</i> , Goldfuss, sp. |

c. Red Chalk of Hunstanton.

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| 36. <i>Cyclolites polymorpha</i> , Goldfuss, sp. | 39. <i>Micrabacia coronula</i> , Goldfuss, sp., and variety. |
| 37. <i>Podoseris mammiliformis</i> , Duncan. | |
| 38. ——— <i>elongata</i> , Duncan. | |

d. Gault.

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| 40. <i>Caryophyllia Bowerbanki</i> , Ed. & H., and a variety. | 46. <i>Cyclocyathus Fittoni</i> , Ed. & H. |
| 41. <i>Trochocyathus conulus</i> , Phillips, sp. | 47. <i>Smilitrochus elongatus</i> , Duncan. |
| 42. ——— <i>Wiltshiri</i> , Duncan. | 48. ——— <i>granulatus</i> , Duncan. |
| 43. ——— <i>Harveyanus</i> , Ed. & H., and five varieties. | 49. ——— <i>insignis</i> , Duncan. |
| 44. <i>Bathycyathus Sowerbyi</i> , Ed. & H. | 50. ——— <i>cylindricus</i> , Duncan. |
| 45. <i>Leptocyathus gracilis</i> , Duncan. | 51. <i>Trochosmilium sulcata</i> , Ed. & H. |
| | 52. <i>Micrabacia Fittoni</i> , Duncan. |

e. Lower Greensand.

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|---|---|
| 53. <i>Brachycyathus Orbignyanus</i> , Ed. & H. | 56. <i>Isastræa Morrisi</i> , Duncan. |
| 54. <i>Smilitrochus Austeni</i> , Ed. & H. | 57. <i>Turbinoseris de-Fromenteli</i> , Duncan. |
| 55. <i>Trochosmilium Meyeri</i> , Duncan. | 58. <i>Holocystis elegans</i> , Lonsdale, sp. |

Micrabacia coronula is common to the Upper Greensand and the Red Chalk, and *Smilitrochus elongatus* is found in the Gault and in the Upper Greensand.

* The six species from Haldon marked * were described by me after the reading of this Report (see Pal. Soc. vol. for 1869).

The number of species of *Madreporaria* in the British Cretaceous formations is therefore fifty-eight.

MM. Milne-Edwards and Jules Haime had described twenty-three species before this Report was commenced; of these I have ventured to suppress *Parasmilia Mantelli*, *Trochocyathus Konigi*, and *Trochocyathus Warburtoni*.

The coral-fauna of the British area was by no means well developed or rich in genera during the long period during which the Cretaceous sediments were being deposited. The coral tracts of the early part of the period were on the areas now occupied by the Alpine Neocomian strata, and those of the middle portion of the period were where the Lower Chalk is developed at Gosau, Uchaux, and Martigues.

There are no traces of any coral-reefs or atolls in the British Cretaceous area, and its corals were of a kind whose representatives for the most part live a depth of from 30 to 600 fathoms.

Corals from the Oolitic Strata.

The following authors have contributed to our knowledge of the Oolitic Corals:—Parkinson, 'Organic Remains,' 1808. W. Conybeare and W. Phillips, 'Outlines of the Geol. of Eng. and Wales,' 1822. Fleming, 'British Animals,' 1828. E. Bennet, 'Cat. Org. Remains, Wilts,' 1837. Fitton, "Strata below the Chalk," Geol. Trans. 2nd series, 1843. Morris, 'Cat. of British Fossils,' 1843. MM. Milne-Edwards and Jules Haime, 'Monog.' (Pal. Soc.) 1851. M'Coy, Ann. Nat. Hist. 1848 (several essays). W. Smith, 'Strata Identified,' 1816. J. Phillips, 'Geol. of Yorkshire,' 1829. R. C. Taylor, Mag. Nat. Hist. 1830. S. Woodward, 'Synopt. Table of Org. Rem.' 1830. G. Young, 'Geol. Survey of York,' 1828. R. Plot, 'Nat. Hist. Oxfordshire,' 1676. J. Walcott, 'Descr. and Fig. of Petref. found near Bath,' 1779. T. Wright, M.D., F.G.S., Cotteswold Club Trans. 1866.

An analysis of the work of these authors, with the exception of that of Dr. Wright, is found scattered over the pages of MM. Milne-Edwards and Jules Haime's "Monograph of the Oolitic Corals," Pal. Soc. 1851. No new species of fossil Corals have been described from the Oolitic rock since that date. During the last year I have added to the species already known five from the Great Oolite, and thirteen from the Inferior Oolite. A careful study of the 251 *Thecosmilæ* of the Inferior Oolite at Crickley has enabled me to distinguish five very remarkable varieties of *Thecosmilia gregaria*, M'Coy, sp., and to satisfy myself that the relations of the *Thecosmilæ* of the Lias to the genera *Isastræa*, *Latimæandra*, and others were repeated in the Inferior Oolite. There are specimens of *Thecosmilia gregaria* in Dr. Wright's collection which, had I not had a considerable series to examine from other sources, might have been associated with Reuss's new genus *Heterogyra*, with *Symphyllia* and *Latimæandra*. The relation of these genera to *Montlivaltia* has been noticed (except *Heterogyra*) in the first Report (Brit. Assoc. Report, Norwich, p. 106 *et seq.*), and there is a clear proof that the same phenomena of evolution may occur consecutively. That is to say, the St.-Cassian *Montlivaltia* and *Thecosmilæ* varied and became permanent, compound, and serial corals of such genera as *Elysastræa*, *Isastræa*, and *Latimæandra*: then the Liassic *Thecosmilæ* did the same; and now it is evident that a *Montlivaltia* of the Inferior Oolite occasionally took on fissiparous growth, and superadded to others a marginal gemmation and a serial growth, and evolved forms which cannot be distinguished from those of the genera above mentioned and *Symphyllia* and *Heterogyra*. There was evidently an inherent power of variation which declared itself in the same direction during the ages which witnessed

the formation of the St. Cassian and the Liassic and the Lower Oolitic deposits ; and it is impossible to deny a genetic value to these oft-repeated structural phenomena.

One of the *Thecosmilice* from the Inferior Oolite at Crickley, which I have named *T. Wrighti*, is very closely allied to the Lower-Liassic species.

It is interesting to find the genus *Cyclolites* represented in the Inferior Oolite by two well-marked species, one of which is like the rest of the forms of the genus in shape, and the other is exceptional in its trochoid form. This last species has, however, all the characteristics of the genus. The *Cyclolites* are extinct; they flourished in the Lower Cretaceous seas, and lasted during the Miocene. MM. Milne-Edwards and Jules Haime (Hist. Nat. des Corall.) mention that the genus originated in the Jurassic age, but they give no evidence. The species now under consideration are, however, clearly from the Inferior Oolite.

A form belonging to a new genus of the *Fungidae* was found by Mr. Mansel at East Coker in the Inferior Oolite. In general shape and the arrangement of the calices the specimen resembles *Dimorphostrea*; but the synapticalæ between the septa and costæ necessitate its association with the *Fungidæ*. There is a central calice, and the others are in a circle around it, being separated by long horizontal septo-costal prolongations; the whole is surrounded by an epitheca, and forms a turbinate shape, the free surface being flat and circular. The genus foreshadows the genera *Cyathoseris* and *Trochoseris* of the Lower Chalk.

There are several new species of the genus *Thamnastræa*; *T. Browni*, nobis (MS. sp.), is remarkable for having in some specimens a long stalk surmounted by a knob-shaped head. The calices are small on the stalk, and very large on the head; so that when the form is examined before it is mature, there is a danger of producing two species instead of one. The stalk often attains the height of 3 or 4 inches. In other specimens there is no stalk, and the knob-shaped corallum is sessile.

A large specimen of *Thamnastræa Manseli* (MS. sp.), Inferior Oolite, is pedunculate, short, and very expanded superiorly; the epitheca is well preserved, and the endothecal dissepiments can be seen. This is a very satisfactory species, and I have had it very carefully drawn, so that the suspiciously synaptical endotheca can be proved to be really dissepimental.

A specimen of *Cladophyllia Bubeana*, d'Orb., sp., figured in the inedited plates of the Palæontographical Society at my instance, is remarkable from the disposition of the corallites to combine and form serial and fissiparous calices as in *Thecosmilice*.

The new species of the genera *Cyathophora* and *Isastræa* are well marked, and that of the last is a dendroid form.

MM. Milne-Edwards and Jules Haime collected and described the following Oolitic species* in their 'Monograph' (Pal. Soc.), 1851:—

Portland Stone.

1. *Isastræa oblonga*, Fleming, sp.

Coral Rag.

1. *Stylina tubulifera*, Phillips, sp.
2. — *De la Bechi*, Ed. & H.
3. *Montlivaltia dispar*, Phillips, sp.
4. *Thecosmilice annularis*, Fleming, sp.
5. *Rhabdophyllia Edwardsi*, M'Coy, sp.

6. *Cladophyllia Stokesi*, Ed. & H.
7. *Cladophyllia cespitosa*, Con. & Phil., sp.
8. *Goniocora socialis*, Römer, sp.
9. *Isastræa explanata*, Goldfuss, sp.
10. — *Greenoughi*, Ed. & H.
11. *Thamnastræa arachnoides*, Parkins., sp.
12. — *concinna*, Goldfuss, sp.
13. *Comoseris irradians*, Ed. & H.
14. *Protoseris Waltoni*, Ed. & H.

* There are three species common to the Great Oolite and the Inferior Oolite, and one is common to the Coral Rag, the Great and the Inferior Oolite. The varieties of *Thecos-*

Great Oolite.

1. *Stylina conifera*, Ed. & H.
2. — *solida*, M'Coy, sp.
3. — *Ploti*, Ed. & H.
4. *Cyathophora Luciensis*, d'Orb., sp.
5. — *Pratti*, Ed. & H.
6. *Convexastræa Waltoni*, Ed. & H.
7. *Montlivaltia Smithi*, Ed. & H.
8. — *Waterhousei*, Ed. & H.
9. *Calamophyllia radiata*, Lamouroux, sp.
10. *Cladophyllia Babeana*, d'Orb., sp.
11. *Isastræa Conybeari*, Ed. & H.
12. — *limitata*, Lamouroux, sp.
13. — *explanulata*, M'Coy, sp.
14. — *serialis*, Ed. & H.
15. *Clausastræa Pratti*, Ed. & H.
16. *Thamnastræa Lyelli*, Ed. & H.
17. — *mammosa*, Ed. & H.
18. — *scita*, Ed. & H.
19. — *Waltoni*, Ed. & H.
20. *Anabacia orbulites*, Lamouroux, sp.
21. *Comoseris vermicularis*, M'Coy, sp.
22. *Microsolena regularis*, Ed. & H.
23. — *excelsa*, Ed. & H.

Inferior Oolite.

1. *Discocyathus Eudesi*, Michelin, sp.
2. *Trochocyathus Magnevillianus*, Michelin, sp.
3. *Axosmilia Wrighti*, Ed. & H.
4. *Montlivaltia trochoides*, Ed. & H.
5. — *tenuilamellosa*, Ed. & H.
6. — *Stutchburyi*, Ed. & H.
7. — *Wrighti*, Ed. & H.
8. — *cupuliformis*, Ed. & H.
9. — *De la Bechi*, Ed. & H.
10. — *lens*, Ed. & H.
11. — *depressa*, Ed. & H.
12. *Thecosmilia gregaria*, M'Coy, sp.
13. *Latimæandra Flemingi*, Ed. & H.
14. — *Davidsoni*, Ed. & H.
15. *Isastræa Richardsoni*, Ed. & H.
16. — *tenuistriata*, M'Coy, sp.
17. — *Lonsdalei*, Ed. & H.
18. *Thamnastræa Deffranciana*, Michelin, sp.
19. — *Terquemi*, Ed. & H.
20. — *Mettensis*, Ed. & H.
21. — *fungiformis*, Ed. & H.
22. — *M'Coyi*, Ed. & H.
23. *Anabacia hemispherica*, Ed. & H.

Mr. Walton has forwarded me *Zephrentis*? *Waltoni*, Ed. & H., from the Inferior Oolite at Dundry, which MM. Milne-Edwards and Jules Haime felt inclined to think was a *remanié* fossil. There is no doubt about the specimen being a *Zephrentis*, and it is clear that it was derived from an older rock, just as the Carboniferous corals mixed up with the Lower-Lias corals were.

I can add the following species to the list of Oolitic fossil corals, and most of them have been figured, but are not yet published (in 6 plates of the Pal. Soc.):—

*New Species.**Great Oolite.*

1. *Thecosmilia obtusa*, d'Orb.
2. *Cyathophora insignis*, nobis.
3. — *tuberosa*, nobis.
4. *Thamnastræa Browni*, nobis.
5. *Isastræa gibbosa*, nobis.

Inferior Oolite.

1. *Montlivaltia Holli*, nobis.
2. — *Tenminckii*, nobis.

3. *Montlivaltia Morrisi*, nobis.
4. *Thecosmilia Wrighti*, nobis.
5. *Thamnastræa Walcottii*, nobis.
6. — *Manseli*, nobis.
7. — *Etheridgii*, nobis.
8. *Isastræa Crickleyi*, nobis.
9. — *dendroides*, nobis.
10. *Dimorphoseris Oolitica*, nobis.
11. *Cyclolites Lyceti*, nobis.
12. — *Beanii*, nobis.

The fauna may be divided as follows:—

	Species.
Portland Stone	1
Coral Rag	14
Great Oolite	28
Inferior Oolite	35
	78

The Oolitic corals, as a whole, indicate the geographical conditions incident to reefs and atolls, and do not represent those bathymetrical states which the Upper and Middle Liassic coralliferous strata appear to have illustrated. A deep-sea coral-fauna is not found amongst the relics of the Oolites, and the

milia gregaria are not mentioned or considered as species, although they have a very fair claim. There are three varieties very Symphyllian, and two very Heterogran in their aspect. There is a well-marked variety of *Montlivaltia trochoides* at Painswick in the Inferior Oolite.

forms peculiarizing the reefs are positively aggregated in an upper and lower mass at Crickley on the Inferior Oolitic beds.

Dr. Wright noticed some years since* an Oolitic coral-reef near Frith Quarry, on the northern spur of Brown's Hill, about two miles from Stroud. There is a corresponding reef on the opposite side of the valley, the whole of the intervening space having been excavated by denudation. The coral-bed consists of large masses of coralline limestone imbedded in a fine-grained cream-coloured mudstone. The corals are in a highly crystalline state, so that the genera and species are determined with difficulty. The bed is from 15 to 20 feet in thickness, and forms one of the finest examples of fossil coral-reefs that Dr. Wright is acquainted with in the district. The bed may be traced along the escarpment, in a north-westerly direction, for several miles, to Witcomb and Crickley on the west, and to near Cubberley and Cowley on the east, where it was worked several years ago. Judging from the thickness of the bed, and the abundance of corals it contains, it must have formed a barrier reef of considerable magnitude in the Jurassic sea. The following is a section showing the relative position of the Lower Coral-reef.

Section of the Lower Coral-reef, in the Inferior Oolite, at the Quarry, North Frith Wood, near Brown's Hill, Gloucestershire.

Lithological Characters and Thickness.	Beds.	Organic Remains. Leading Fossils.
	UPPER FREESTONES.	
Cream-coloured Marl, with several inconstant layers of Mudstone, upper part passing into a loose, friable Freestone, with large <i>Terebratula fimbria</i> . From 20 to 25 feet.	OOLITE, MARL. MIDDLE CORAL-BED.	<i>Thamnostrea</i> , <i>Isastraea</i> , <i>Arosmilus</i> , <i>Terebratula fimbria</i> , <i>T. carinata</i> , <i>T. maxillata</i> , <i>Rhynch. Lacetii</i> , <i>Lucina Wrighti</i> , <i>Lima pontons</i> .
Fine-grained Oolitic Limestone, very white, and emitting a metallic ring when struck with a hammer. 40 to 50 feet.	FREESTONES.	Shelly fragments, not determinable.
Coarse brown ferruginous Oolite.	LOWER RAGSTONES.	<i>Terebratula plicata</i> .
Masses of Coralline Limestone, imbedded in a light-coloured Mudstone; the Corals highly crystalline, forming the chief part of the bed. 15 to 25 feet.	LOWER CORAL-REEF.	<i>Lutinaeandra</i> , <i>Thamnostrea</i> , <i>Isastraea</i> , <i>Arosmilus</i> , <i>Therapsmilus</i> , <i>Pecten Deaulqui</i> , <i>Trichites</i> , <i>Lucina Wrighti</i> .
Brown ferruginous Pisolitic rock. Pea-grit structure not much exposed.	PEA-GRIT.	<i>Lima sulcata</i> , <i>Hinnites abjectus</i> , <i>Ceromya bifoculata</i> , <i>Avicula complicata</i> , <i>Nerita costata</i> , <i>Trochotoma carinata</i> , <i>Eggaster</i> , <i>Hybo-clypeus</i> , <i>Diadema</i> .

* Dr. Wright has kindly sent me these details. See "On Coral-Reefs," by T. Wright, M.D., F.G.S., Cotteswold Club.

The Middle Coral-bed is included in the Oolite Marl, and in some localities as at Frith, Leckhampton, Sheepscombe, and others, it contains masses of corals.

The Upper Coral-reef occupies the horizon of the upper Trigonía Grit, and is very well exposed in many sections. That of Cleve Hill has yielded the best corals. The following section is open near Frith. Ascending the bank above this quarry for a short distance some fields of arable land are passed over, on which are several heaps of the Upper Ragstones, with *Trigonía costata*, *Gryphæa subloba*, and other shells of the higher zone. Walking in the direction of the Grove, after passing over the summit of the hill and descending a short distance, a good section of the upper reef may be seen in the Slad Valley.

Section of the Quarry at Worgin's Corner, Upper Zone of Inferior Oolite.*

Lithology.	Beds.	Organic Remains.
Masses of Coralline Limestone, 4 feet thick.	UPPER CORAL-REEF.	<i>Thamnastræa</i> , <i>Isastræa</i> , <i>Thecosmilia</i> , <i>Magnolia</i> <i>Forbesi</i> , <i>Stomechinus in-</i> <i>termedius</i> , <i>Pecten</i> , <i>Trigo-</i> <i>nia costata</i> .
Hard shelly Limestone, full of the shells of Brachiopoda, 5 feet.	TEREBRATULA-GLOBATA BED.	<i>Terebratula globata</i> , <i>Rhynchonella spinosa</i> , <i>Pholadomya fidicula</i> , <i>P. Heraulti</i> , <i>Ostræa</i> , <i>Gervilla</i> , <i>Trichites</i> .
Hard shelly sandy Oolite, full of <i>Gryphæa</i> , 6 feet.	GYPHÆA BED.	<i>Gryphæa subloba</i> , <i>Lima proboscidea</i> .

The remarkable varieties of *Thecosmilia gregaria*, which resemble the genus *Symphyllia* and *Heterogyra*, are found principally in the lower reef, but they exist in the upper also. Some species appear to be peculiar to the different reefs, but it is unsafe to form lists at present. There is evidently a considerable affinity between the faunas of the reefs, and there is nothing to indicate anything more than a temporary absence from, and a return of the species to an area.

The corals of the Great Oolite are found in the Upper Ragstones underlying the Bradford Clay. Near Bath large masses of *Calamophyllia radiata* are associated with the roots, stems, and heads of *Apicrinites rotundus*, Mill., which flourished like a miniature forest on the reef, and luxuriated amongst the polypes until the clear water was invaded by a current charged with mud, which destroyed the Encrinites and the Corals also†.

The Coral Rag in Wiltshire is divisible into (1) Upper Calcareous Grit, (2) Coral Rag, (3) Clay, (4) Lower Calcareous Grit. It is in the Coral Rag proper (2) that the Coral-beds are found. Of these Mr. Lonsdale‡ remarks :

* See Dr. Wright's pamphlet.

† Dr. Wright, *op. cit*

‡ "Oolitic District of Bath," Trans. Geol. Soc. 2nd ser. vol. iii. p. 261.

"The irregular beds of Polyparia consist of nodules or masses of crystallized carbonate of lime, which afford, invariably, evidences of the labours of the Polypus; and associated with them are others of earthy limestone, which bear only partial proofs of an organic origin. The whole are connected by a pale bluish or yellowish stiff clay. It happens frequently that a bed is composed of one genus of Polyparia."

In Yorkshire the Coralline Oolite is well developed, and several reefs are found at Hackness, Ayton, Seamer, &c. John Leckenby, Esq., F.G.S., of Scarborough, gives the following details (see Dr. Wright, *op. cit.*):—

"In various parts of the district occupied by the Coralline Oolite around Scarborough are found patches of coral-reef sometimes occupying an area of fully an acre; and although never attaining an altitude so high as the beds on the inclined surfaces of which they rest, they are truly the uppermost beds of the formation.

"They are sometimes from 10 to 15 feet in thickness, and consist of a series of layers of crystallized coral from 18 to 24 inches in thickness, of the species *Thamnastræa concinna*, Goldf. (which is the *T. micraston*, Phillips), each layer being separated by rubbly clay and mud, in all probability being the decomposition of each successive reef. The rock is quarried to supply material for repairing the roads of the district; but it is by no means so well adapted for the purpose as the adjacent calcareous grit, which, at the cost of a little additional labour, would furnish a material much more durable. The crystalline coral-reef is quickly ground to powder, and its use affords less satisfaction to the traveller than to the geologist, as the blocks which are stored up for use along the sides of the road yield many a handsome specimen to adorn his collection.

"The largest deposit is near the village of Ayton: there are others not quite so extensive; one near the village of Seamer, another close to the hamlet of Irton, and others in the neighbourhood of Wykeham and Brompton—the intervening distances being about a mile in every case."

Messrs. Leckenby and Cullen visited the coral-reefs of the Coralline Oolite near Scarborough with Dr. Wright, who writes as follows:—

"One quarry, near Ayton, which may be considered as a type of the others, consisted of masses of crystalline coralline limestone, the beds having an irregular undulating appearance. The corals appear to have grown in areas of depression of the coralline sea; the rock consists of large masses of highly crystalline limestone, forming nodulated eminences and concave curves, in beds of from 12 to 18 inches in thickness, having a stratum of yellowish clay filling up the hollows, and forming a horizontal line again to the stratification; then follows another stratum of crystalline limestone, which assumes the same nodulated condition as the one below it, the surface of the coral masses, where exposed, showing that the whole is almost entirely composed of a small-celled *Astræa*, *Thamnastræa concinna*, Goldf., *Micraston*, Phillips, in some altered condition; the reef is exposed to about 10 feet in section, and rests on another, forming the floor of the quarry, and which descends many feet deeper; the corals are bored by *Gastrochaena*, and numerous shells were seen imbedded in the coral mass, which had nestled in the crannies of the reef."

Dr. Wright sums up with regard to the French, German, and British strata of the Étage Corallien as follows:—

"From this general view of the geographical distribution of the Coralline zone, it would appear that this formation was composed of a series of coral-reefs in the Jurassic sea, which, during the period of their construction, occu-

pied a large portion of the region now constituting the soil of modern Europe; and that the bed of the Jurassic sea was a slowly subsiding area of great extent, like many parts of the Coral Sea in the Indo-Pacific Ocean of our day" *.

The restriction of species to very definite areas, and to limited zones amongst these succeeding coral-reefs, is very remarkable, and, as was noticed to occur in the Lias, the corals are occasionally persistent, and are associated with different molluscan species. But the physico-geological changes which produced new reefs must have been preceded by considerable geographical changes, for, as a rule, the species of the grand divisions of the Jurassic system are different. *Thecosmilia Wrighti* of the lower reef of the Inferior Oolite has considerable resemblance to the *Thecosmilicæ* of the Inferior Lias; but no Liassic species pass upwards into the Oolites. Only four species are common to the Inferior and Great Oolites, and one to the Coral Rag and Great Oolite; yet there was a succession of the physico-geographical conditions favourable for the formation of reefs on the same area. The existence of reefs in so high a latitude during the Oolitic period, and their formation by polypes whose genera were all extinct during the early Cainozoic period, but which are clearly represented by allied genera in the existing reefs, are very suggestive. These were the last reefs of the British area; for there are no traces of agglomeration of reef-building genera in the Lower Greensand, the Gault, Upper Greensand, Chalk, or Tertiary formations. The nearest approach to a reef must have been in the Lower Oligocene period, when the Tabulate corals and *Solenastrææ* of Brockenhurst formed a small outlier of the European coral sea of the time between the Nummulitic age and the lowest Falunian deposits.

The succession of reefs and deep-sea or littoral coral conditions appears to have been as follows on the British area south of Yorkshire, after the termination of the Permian period:—

Triassic	No corals (dry land).
Rhætic	Few corals. Littoral and deep water, from 5 to 200 fathoms.
L. Lias { Zone of <i>Amm. planorbis</i> ..	Scattered reefs and littoral corals.
" <i>angulatus</i> ..	Barrier reefs and deep-water corals.
" <i>Bucklandi</i> ..	Scattered reefs and deep-water corals.
Middle Lias	No reefs. Littoral and deep-water corals.
Upper Lias	No reefs. Littoral and deep-water corals.
Inferior Oolite	Successive reefs.
Great Oolite	Successive reefs.
Coral Rag	Reefs.
Portland Oolite	Reefs rare. No other corals.
Lower Greensand	Littoral and deep-sea corals. No reefs.
Gault	Littoral and deep-sea corals. No reefs.
Red Chalk	Littoral and deep-sea corals. No reefs.
Upper Greensand	Littoral corals. No reefs †.
Lower and Upper Chalk	Deep-sea corals. Few littoral corals.
Eocene	Deep-sea corals. No reefs. Littoral corals.
Lower Oligocene	Deep-sea corals. Scattered reefs. Littoral corals.
Crag	Deep-sea corals. No reefs. Littoral corals.
Recent	Deep-sea corals. No reefs. Littoral corals.

* Dr. Wright, *op. cit.*

† Deep-sea and small reefs in the west.

The reefs were doubtless developed on areas where depression and elevation of the sea-bottom was constant, and where old rocks were occasionally sufficiently near the surface to afford a nidus for reef-species. The depths around these rocks must have been considerable; there could not have been any large bodies of fresh water near, and the sea-water must have been pure and in constant motion. The littoral corals resembled the *Caryophyllia Smithi* of our coasts in bathymetrical distribution, and the deep-sea corals, like the existing *Caryophyllia borealis* and *Lophohelia prolifera*, were simple solitary forms distributed at a depth of from 30 to 600 or more fathoms.

The British reefs of the early Secondary period were not necessarily situated in a tropical climate; for there is no reason why reef-building corals should not have been able to exist and multiply in the same temperature of sea-water that deep-sea corals now do. The deep-sea corals are abundant between Norway and the Shetlands, and are quite out of the range of the Gulf-stream. The Bermuda reefs are dependent upon the Gulf-stream for the supply of sufficiently warm water to produce the development of ova. It may have happened that the early Secondary species may not have required a greater amount of sea-temperature than that in which the great coral called *Dentrophyllia ramea* flourishes off Cadiz. These facts and considerations must have some weight against the argument that, because all existing reefs are tropical, all former reefs must have been so.

If the area of Europe is compared with that of Great Britain during the periods that have elapsed since the Palæozoic epoch, the distribution of reefs and centres of oscillation, and of deep-sea and littoral corals indicating very stationary conditions, gives a very good idea of the successive physico-geographies of the old seas.

		Great Britain.	Rest of Europe.
Trias		Uncoralliferous	Reefs in St. Cassian district.
Rhætic.....		Few deep-sea and littoral corals.	Reefs in Lombardy and Switzerland.
Lower Lias.	{ Zone of <i>Amm. planorbis</i>	Scattered reefs and deep-sea and littoral corals.	Scattered reefs in France, Lombardy, and Switzerland.
	„ <i>angulatus</i>	Barrier reefs, deep-sea and littoral corals.	Reefs in Switzerland. Vast areas with simple deep-sea and littoral corals in France.
	„ <i>Bucklandi</i>	Scattered reefs	Rare deep-sea corals in Europe.
Middle Lias		Deep water and littoral corals.	Rare deep-sea corals.
Upper Lias		Very uncoralliferous	Very uncoralliferous.
Inferior Oolite		Successive reefs	Reefs in Western Europe.
Great Oolite		Successive reefs	Reefs in Western Europe.
Coral Rag		Few reefs.....	Few reefs.
Portland Oolite		Reefs rare	Reefs rare.
Neocomian		Littoral and deep-sea corals.	Reefs in France, Switzerland, Germany.
Gault		Littoral and deep-sea corals.	Littoral and deep-sea corals.
Cenomanian		Littoral corals	Scattered reefs in France and Western Germany.
Lower Chalk		Deep-sea corals	Reefs in France, Spain, Switzerland, Germany.
Upper Chalk		Deep-sea corals	Few reefs and deep-sea corals.
Eocene.....		Deep-sea corals and a few littoral.	Reefs in the Lombardo-Swiss, Pyrenean, and Austrian areas.

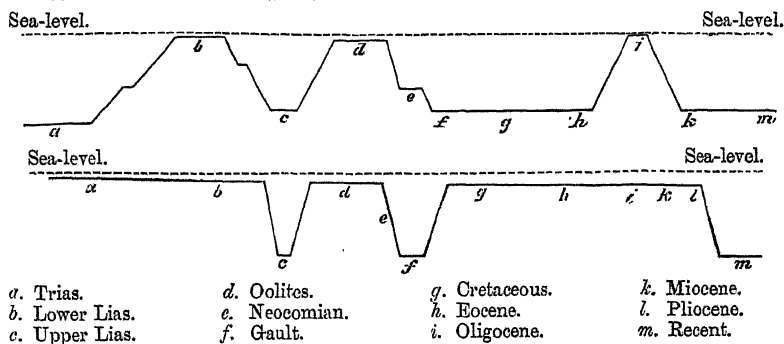
	Great Britain.	Rest of Europe.
Lower Oligocene	Scattered reefs	Reefs in the Vicentin; deep-sea corals in Germany, and littoral species also.
Crag.....	Deep-sea corals and littoral corals.	Deep-sea and littoral species in Sicily, south of Spain, Belgium. Reefs very rare.
Recent	Deep-sea and littoral species.	Deep-sea and littoral species in the Mediterranean and western seas of Europe.

The Miocene reefs were in South France, Italy, Spain, and Germany, where there were also deep-sea and littoral species.

The seas of Europe and Great Britain during the period of the Middle and Upper Lias were most uncoralliferous, and also during the deposit of the Gault. On the other hand, there were reef and atoll seas during the deposition of the sediments of the zone of *A. angulatus* and *bisulcatus* of the Lower Lias, of the Inferior and Great Oolite, and of the Oligocene.

The European area was more or less a centre of oscillation and of reef-formation during the Triassic and the Lower-Liassic periods, during the Lower-Oolitic periods, and from the Neocomian to the end of the Miocene, inclusive of these periods. There was a great change in the depth of the seas and of the physico-geographical conditions after the formation of the deposits containing *A. Bucklandi*, and a second change produced the reefs of the Oolites. Again, the deposits of the Portland Oolite and the Gault were preceded and followed by great bathymetrical changes.

The changes on the British area were before the Lower Lias and after it, after the Great Oolite and Coral Rag, and after the Eocene and before the Crag. Whilst the European area was coralliferous in the Trias, the British area was uncoralliferous; and whilst the Cretaceous reefs of Western Europe flourished, the British area was characterized by deep-sea and littoral corals. The lines and curves which may be drawn to explain these variations in the two areas are as follows* :—



The reef-areas of the Upper Lias and Gault have yet to be discovered.

It is very remarkable that the Tabulate corals, which were so abundant in the Palæozoic Coral-fauna, and which constitute whole reefs at the present time, should not be represented in the British Secondary Coral-fauna. The first trace of them is found in the Eocene beds. The perforate corals, omitting the Fungidæ, which are not included in them by M.M. Milne-Edwards and Jules Haime, are unknown in the Secondary rocks of Great Britain,

* The upper diagram refers to the British area, and the lower to the European. The "a" commences at the upper part of the Trias.

yet they form masses of existing reefs, and were abundant in the Oligocene. One of the class, *i. e.* the *Protaræa vetusta*, appeared in the Lower Silurian formation of Ohio; but the class was not apparently represented on our area until the Eocene, if we except the *Microsolenas*, which are very exceptional perforate forms of the Oolites. The absence of these forms must be accounted for by the deficiency of the geological record.

		<i>Enumeration of Species.</i>	<i>Species.</i>
Cainozoic.	{	Crag	4
		Lower Oligocene	13
		Eocene	38
		Upper } Chalk	19
		Lower }	
		Upper Greensand	16
		Red Chalk	4
		Gault	13
Mesozoic.	{	Lower Greensand	6
		Portland Oolite	1
		Coral Rag	14
		Great Oolite	28
		Inferior Oolite	35
		Upper Lias	1
		Middle Lias	2
	{	Lower Lias	65
			259

List of Tertiary and Secondary British Fossil Corals.

Crag.

- Sphenotrochus intermedius*, *Münster*, sp. *Cryptangia Woodii*, *Ed. & H.*
Flabellum Woodii, *Ed. & H.* *Balanophyllia calyculus*, *Wood.*

Oligocene.

- Solenastrea cellulosa*, *Duncan.* *Lobopsammia cariosa*, *Goldfuss*, sp.
 — *Kœneri*, *Duncan.* *Axopora Michelini*, *Duncan.*
 — *Reussi*, *Duncan.* *Litharæa Brockenhursti*, *Duncan.*
 — *gemmans*, *Duncan.* *Madrepora Anglica*, *Duncan.*
Beyrichi, *Duncan.* — *Römeri*, *Duncan.*
 — *granulata*, *Duncan.* — *Solanderi*, *DeFrance.*
Balanophyllia granulata, *Duncan.*

Eocene.

- Turbinolia sulcata*, *Lamarck.* *Paracyathus cylindricus*, *Duncan.*
 — *Dixonii*, *Ed. & H.* *Dasmia Sowerbyi*, *Ed. & H.*
 — *Bowerbanki*, *Ed. & H.* *Oculina conferta*, *Ed. & H.*
 — *Fredericiana*, *Ed. & H.* — *incrustans*, *Duncan.*
 — *humilis*, *Ed. & H.* — *Wetherolli*, *Duncan.*
 — *minor*, *Ed. & H.* *Diplobelia papillosa*, *Ed. & H.*
 — *firma*, *Ed. & H.* *Stylocenia emarciata*, *Lamarck*, sp.
 — *Prestwichi*, *Ed. & H.* — *monticularia*, *Schweigger*, sp.
 — *affinis*, *Duncan.* *Astrocerenia pulchella*, *Ed. & H.*
 — *exarata*, *Duncan.* *Stephanophyllia discoides*, *Ed. & H.*
 — *Forbesi*, *Duncan.* *Balanophyllia desmophyllum*, *Lonsdale*, sp.
Leptocyathus elegans, *Ed. & H.* *Dendrophyllia elegans*, *Duncan.*
Trochocyathus sinuosus, *Brongniart*, sp. — *dendrophylloides*, *Lonsdale.*
 — *Austeni*, *Duncan.* *Stereopsammia humilis*, *Ed. & H.*
 — *insignis*, *Duncan.* *Dendraceis Lonsdalei*, *Duncan.*
Paracyathus crassus, *Ed. & H.* *Porites panicea*, *Lonsdale.*
 — *caryophyllus*, *Lamarck*, sp. *Litharæa Websteri*, *Bowerbank*, sp.
 — *brevis*, *Lamarck*, sp. *Axopora Forbesi*, *Duncan.*
 — *Haimeii*, *Duncan.* — *Parisiensis*, *Michelin.*

Chalk.

- Caryophyllia cylindracea, *Reuss*, sp.
 — Lonsdalei, *Duncan*.
 — Tennanti, *Duncan*.
 Onchotrochus serpentinus, *Duncan*.
 Trochosmia laxa, *Ed. & H.*, sp. and varieties 1 2, 3.
 — cornucopiæ, *Duncan*.
 — Wiltshiri, *Duncan*.
 — Woodwardi, *Duncan*.
 — granulata, *Duncan*.
 — cylindracea, *Duncan*.
 Parasmilia centralis, *Mantell*, sp., varieties 1, 2.
 — cylindrica, *Ed. & H.*
 — Fittoni, *Ed. & H.*
 — serpentina, *Ed. & H.*
 — monilis, *Duncan*.
 — granulata, *Duncan*.
 Diblasus Gravensis, *Lonsdale*.
 Synhelia Sharpeana, *Ed. & H.*
 Stephanophyllia Bowerbanki, *Ed. & H.*

Upper Greensand.

- Onchotrochus Carteri, *Duncan*.
 Smilotrochus tuberosus, *Ed. & H.*
 — elongatus, *Duncan*.
 — angulatus, *Duncan*.
 Cyathophora monticularia, *D'Orbigny*.
 Favia stricta, *Ed. & H.*
 — minutissima, *Duncan*.
 Thamnastræa superposita, *Michelin*.
 Micrabacia coronula, *Goldfuss*, sp.
 Peplasmilia Austeni, *Ed. & H.*
 — depressa, *E. de From.*
 Placasmilia cuneiformis, *Ed. & H.*
 — Parkinsoni, *Ed. & H.*
 — magnifica, *Duncan*.
 Astrocœna decaphylla, *Ed. & H.*
 Isastræa Haldonensis, *Duncan*.

Red Chalk of Hunstanton.

- Cyclolites polymorpha, *Goldfuss*, sp.
 Podoseris mammiliformis, *Duncan*.
 — elongata, *Duncan*.
 Micrabacia coronula, *Goldfuss*, sp., and variety.

Gault.

- Caryophyllia Bowerbanki, *Ed. & H.*, and a variety.
 Trochocyathus conulus, *Phillips*, sp.
 — Wiltshiri, *Duncan*.
 — Harveyanus, *Ed. & H.*, and 5 varieties.
 Bathycyathus Sowerbyi, *Ed. & H.*
 Leptocyathus gracilis, *Duncan*.
 Cyclocyathus Fittoni, *Ed. & H.*
 Smilotrochus elongatus, *Duncan*.
 — granulatus, *Duncan*.
 — insignis, *Duncan*.
 — cylindricus, *Duncan*.
 Trochosmia sulcata, *Ed. & H.*
 Micrabacia Fittoni, *Duncan*.

Lower Greensand.

- Brachycyathus Orbygnyanus, *Ed. & H.*
 Smilotrochus Austeni, *Ed. & H.*
 Trochosmia Meyeri, *Duncan*.
 Isastræa Morrisi, *Duncan*.
 Turbinoseris de-Fromenteli, *Duncan*.
 Holocystis elegans, *Ed. & H.*

Portland Oolite.

Istræa oblonga, *Fleming*, sp.

Coral Rag.

- Stylina tubulifera, *Phillips*, sp.
 — De la Bechi, *Ed. & H.*
 Montilivaltia disparis, *Phillips*, sp.
 Thecosmia annularis, *Fleming*, sp.
 Rhabdophyllia Edwardsi, *M'Coy*, sp.
 Calamophyllia Stokesi, *Ed. & H.*
 Cladophyllia cæspitosa, *Con. & Phil.*, sp.
 Goniocora socialis, *Romer*, sp.
 Isastræa explanata, *Goldfuss*, sp.
 — Greenoughi, *Ed. & H.*
 Thamnastræa arachnoides, *Parkinson*, sp.
 — concinna, *Goldfuss*, sp.
 Comoseris irradians, *Ed. & H.*
 Protoseris Waltoni, *Ed. & H.*

Great Oolite.

- Stylina conifera, *Ed. & H.*
 — solida, *M'Coy*, sp.
 — Ploti, *Ed. & H.*
 Cyathophora Luciensis, *d'Orb.*, sp.
 — Pratti, *Ed. & H.*
 — insignis, *Duncan*.
 — tuberosa, *Duncan*.
 Convexastræa Waltoni, *Ed. & H.*
 Montilivaltia Smithi, *Ed. & H.*
 — Waterhousei, *Ed. & H.*
 Thecosmia obtusa, *d'Orb.*
 Calamophyllia radiata, *Lamouroux*, sp.
 Cladophyllia Babeana, *d'Orb.*, sp.
 Isastræa Conybeari, *Ed. & H.*
 — limitata, *Lamouroux*, sp.
 — explanata, *M'Coy*, sp.
 — serialis, *Ed. & H.*
 — gibbosa, *Duncan*.
 Clausastræa Pratti, *Ed. & H.*
 Thamnastræa Lyelli, *Ed. & H.*
 — mammosa, *Ed. & H.*
 — scita, *Ed. & H.*
 — Waltoni, *Ed. & H.*
 — Browni, *Duncan*.

Anabacia orbulites, Lamouroux, sp.
Comoseris vermicularis, McCoy, sp.

Microsolena regularis, Ed. & H.
 — *excolsa*, Ed. & H.

Inferior Oolite.

Discocyathus Eudesi, Michelin, sp.
Trochocyathus Magnevilleianus, Michelin, sp.
Axosmilia Wrighti, Ed. & H.
Montlivaltia trochoides, Ed. & H.
 — *tenuilamellosa*, Ed. & H.
 — *Stutchburyi*, Ed. & H.
 — *Wrighti*, Ed. & H.
 — *cupuliformis*, Ed. & H.
 — *De la Bechi*, Ed. & H.
 — *lens*, Ed. & H.
 — *depressa*, Ed. & H.
 — *Holli*, Duncan.
 — *Painswicki*, Duncan.
 — *Morrisi*, Duncan.
Thecosmilia gregaria, McCoy, sp.
 — *Wrighti*, Duncan.
Latimæandra Flemingi, Ed. & H.
 — *Davidsoni*, Ed. & H.

Isastræa Richardsoni, Ed. & H.
 — *tenuistriata*, McCoy, sp.
 — *Lonsdalei*, Ed. & H.
 — *Crickleyi*, Duncan.
 — *dendroidea*, Duncan.
Thamnastræa Defranceana, Michelin, sp.
 — *Torquemi*, Ed. & H.
 — *Mettensis*, Ed. & H.
 — *fungiformis*, Ed. & H.
 — *McCoyi*, Ed. & H.
 — *Walcotti*, Duncan.
 — *Manseli*, Duncan.
 — *Etheridgi*, Duncan.
Anabacia hemispherica, Ed. & H.
Dimorphoseris Oolitea, Duncan.
Cyclolites Lyetti, Duncan.
 — *Beani*, Duncan.

Upper Lias.

Theocyathus Moorei, Ed. & H.

Middle Lias.

Lepidophyllia Hebridensis, Duncan.

Montlivaltia Victoriae, Duncan.

Lower Lias.

Lepidophyllia Stricklandi, Duncan.
Oppelismilia gemmans, Duncan.
Montlivaltia Wallie, Duncan.
 — *Murchisonie*, Duncan.
 — *Ruperti*, Duncan.
 — *parasitica*, Duncan.
 — *simplex*, Duncan.
 — *brevis*, Duncan.
 — *pedunculata*, Duncan.
 — *polymorpha*, Terg. et Piette.
 — *Haimei*, Ch. et Dew.
 — *Hibernica*, Duncan.
 — *papillata*, Duncan.
 — *Guettardi*, Blainville.
 — *nummiformis*, Duncan.
 — *radiata*, Duncan.
 — *patula*, Duncan.
 — *rugosa*, Wright, sp.
 — *mucronata*, Duncan.
Thecosmilia Suttonensis, Duncan.
 — *mirabilis*, Duncan.
 — *serialis*, Duncan.
 — *irregularis*, Duncan.
 — *Torquemi*, Duncan.
 — *affinis*, Duncan.
 — *dentata*, Duncan.
 — *plana*, Duncan.
 — *Brodiei*, Duncan.
 — *Martini*, E. de From.
 — *Michelini*, Terg. et Piette.
Rhabdophyllia rugosa, Laube.
 — *recondita*, Laube.

Astrocenia Sinemuriensis, d'Orb.
 — *gibbosa*, Duncan.
 — *plana*, Duncan.
 — *insignis*, Duncan.
 — *reptans*, Duncan.
 — *parasitica*, Duncan.
 — *pedunculata*, Duncan.
 — *costata*, Duncan.
 — *favoidea*, Duncan.
 — *superba*, Duncan.
 — *dendroidea*, Duncan.
 — *minuta*, Duncan.
Cyathocenia dendroidea, Duncan.
 — *incrustans*, Duncan.
 — *costata*, Duncan.
 — *globosa*, Duncan.
Elysastræa Fischeri, Laube.
 — *Moorei*, Duncan.
Septastræa excavata, E. de From.
 — *de-Fromentoli*, Terquem.
 — *Evershami*, Duncan.
 — *Haimei*, Wright, sp.
Latimæandra denticulata, Duncan.
Isastræa Sinemuriensis, E. de From.
 — *globosa*, Duncan.
 — *Murchisoni*, Wright.
 — *Torresii*, Duncan.
 — *endothecata*, Duncan.
 — *insignis*, Duncan.
 — *Stricklandi*, Duncan.
 — *latimæandroidea*, Duncan.

Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals for Photographing. The Committee consists of HENRY WOODWARD, F.G.S., Dr. DUNCAN, F.R.S., Professor HARKNESS, F.R.S., and JAMES THOMSON, F.G.S. (Reporter).

THE operations of this Committee have been carried on indefatigably during the past year; the results are very promising, but much additional work must be performed before any satisfactory conclusions can be arrived at.

We have cut several hundred sections, but many of them have been so crushed and fractured, that they are absolutely useless for our purpose; thus in one lot of eighty-seven we found only two specimens sufficiently perfect to be of any use; this is to be regretted, as it is desirable to select as perfect specimens as possible for photographing, and also for the use of Dr. Duncan for describing in the Transactions of the Palæontological Society.

Those cut, and partly cut, consist of the following genera:—*Cyathophyllum*, *Cyclophyllum*, *Clisiophyllum*, and allied forms, *Lonsdalia*, *Zephrentis*, *Amplicus*, *Michelinia*, *Syringopora*, *Lithostrotion* and its varieties.

The time and labour involved in superintending the cutting, examining, and finishing those which are sufficiently perfect, will explain the impossibility of producing this year so complete a set as we could have wished. However, we have been sufficiently successful to warrant us in saying that with those made, and others in readiness to make, we will be able to produce in another year a very full set of plates.

With the plates already finished we have been trying a number of experiments in photography; finding that by the usual process the colour fades by exposure to light, we went to Newcastle and examined Mr. Swan's carbon process; and, being satisfied that it was an improvement, we left three plates with him, and we now exhibit the results, satisfactory in two of them, while the other has some defects; we are, however, in hopes that soon we will be able to produce fac-similes on zinc or copper plates. Mr. Swan has been trying experiments for that purpose, and he is in hopes of being successful. If so, we will be able to produce them in any number, and at such a moderate price that they will be available for ordinary publishing purposes. If not successful, we expect to be able, by the carbon process, to produce sets of plates which will be placed in a few of the principal Museums when completed.

Report on Ice as an Agent of Geologic Change. By a Committee, consisting of Professor OTTO TORELL, Professor RAMSAY, LL.D., F.R.S., and H. BAUERMAN, F.G.S. (Reporter).

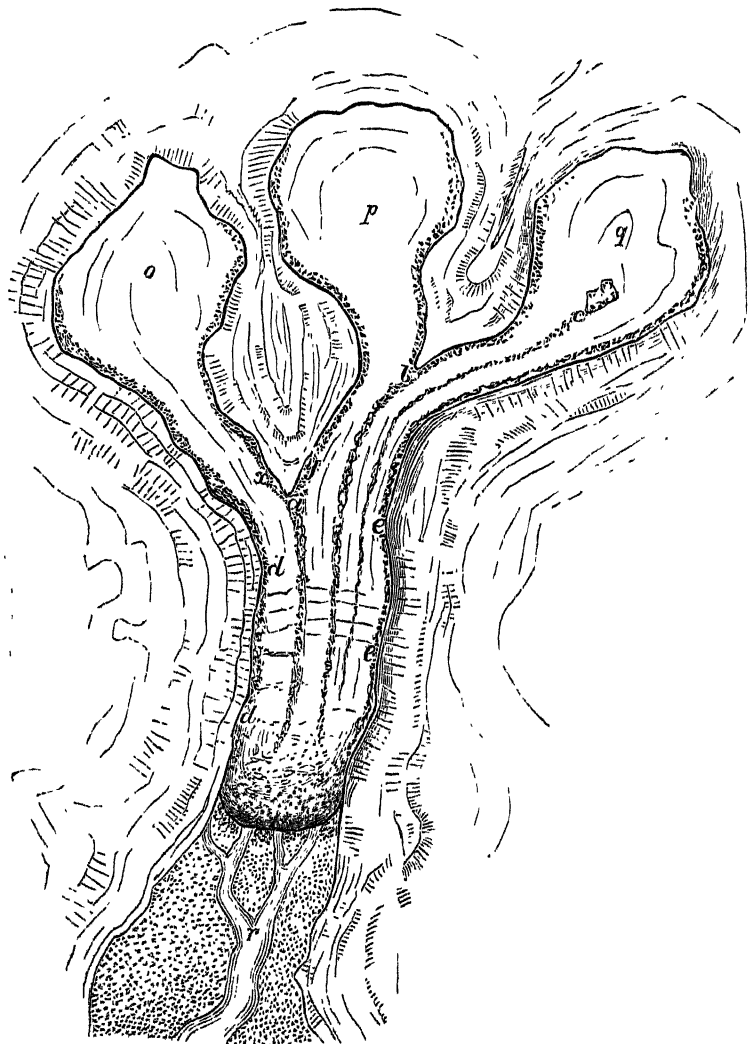
WE are of opinion that the work already done in the investigation of the phenomena connected with ice is not sufficient to enable us to prepare a Report showing the precise effect of "ice as an agent of geologic change;" but enough has been done to show in part the manner in which the subject may be followed, for the purpose of obtaining information as to the quantitative action of glaciers, both as regards their erosive and transporting powers.

First. We would select a well-known glacier-region, such as the Alps, and there for preliminary investigation fix on a large glacier, simple in structure and easily accessible, such, for example, as the lower glacier of the

Aar. If not already done, the glacier and the surrounding mountains ought to be well surveyed and mapped, and its moraines clearly expressed.

Secondly. The amount of rocky and earthy matter forming each medial and lateral moraine would require to be determined as accurately as possible, probably in the manner illustrated by the accompanying rough diagram of an imaginary glacier.

Take of the medial moraine marked *a* a space, say, from 100 to 500 yards in length, and estimate the solid contents of that portion of the moraine. This should be done as near as possible to the place where the medial moraine is formed by the union of the two lateral moraines *x* and *y*; for lower down part



of the material may disappear by falling into crevasses. The same must be done for the moraines *b* and *c*, or for each medial moraine; and also, in several

places, for the lateral moraines *d* and *e*. Then ascertain the rates of the onward movement of the glacier, according to circumstances, in various portions of its length, and at various seasons of the year; and by these means will be ascertained to a great extent (but not precisely) the quantity of matter carried annually on the surface of the glacier to its termination, and this matter will represent a very large part of the waste of the sides of the mountains that bound the snow and glacier basins *o*, *p*, *q*, and the sides of the mountains that bound the glacier lower down towards its terminal moraine.

Thirdly. The chief part of the *remainder* of the rocky and earthy matter that is carried from the mountains to the level of the glacier will pass under it at its sides, and mingle with the material that finds its way to the bottom of the glacier through the means of crevasses and moulins, and also with that which is the product of the erosive action of the glacier exerted on its bed and on the stone blocks imprisoned at the bottom of the ice. A small part of the above-named *remainder* may also be caught in the ice and imprisoned in rejoined crevasses.

Fourthly. We see no way of precisely estimating the amount of erosion produced by the weight and movement of the glacier—that is to say, the rate at which any given glacier may deepen and widen its valley by pure wearing action, owing to the circumstance that the sediments discharged along with the water that flows from the end of a glacier do not represent the amount produced by mere erosive force, for the reason stated under head 3. But it is essential to the main question that correct estimates should be made of the amount of solid matter brought from under the glacier by the help of running water, and also of the amount carried away by the continual wasting by streams of the terminal moraine.

As regards the matter in suspension in the river, and also that forced along its bottom, it should be estimated, if possible, at a point *r*, just below where the various streams unite that flow from the ends of most great glaciers. Where there is only one stream (as in the Aletsch glacier), the closer to the glacier the better. The operation would be very laborious; for, unless frost and snow prevented it, it would require to be done for every day in a year or years, and several times each day, at least in summer and autumn, and probably in spring and winter also. For example, in summer the quantity of water varies largely, according to the heat of various periods of the day; and it would probably be necessary to make an observation every day before sunrise, another some time before noon, another between four and six o'clock in the afternoon, and another after nightfall; in fact sufficiently often to obtain an average for each day in the year.

With regard to the transport of heavier matter from the terminal moraine (which forms a portion of this part of the subject) by the glacier-streams that waste it, an index to the amount may approximately be obtained by means of the estimates indicated under head 2, assuming that all terminal moraines are formed chiefly from matter transported on the surface of the glacier.

Other methods involving special study on the spot would be required for the terminal and lower side-moraines of such glaciers as those of La Brenva and Miage, which on the sides that face up the valley towards the Lake of Comballe are still growing.

Fifthly. If the foregoing methods are correct, they might afterwards be applied to all the glaciers of the Alps, and the rate of waste and transport by glacier-action might be approximately determined; and in like manner

they might also be used for well-known and comparatively accessible mountain-ranges like the Scandinavian chain, the Himalaya, the mountains of New Zealand, and in time to the Rocky Mountains, the Andes, and others.

Sixthly. But the above only forms part of the subject, and to attempt to estimate the existing importance of "ice as an agent of geologic change," the *glacier* and *glacial* phenomena generally as regards erosion and terrestrial and marine transport of material must be taken into account in such regions as Spitzbergen, Greenland, and Victoria Land in the southern hemisphere. Something on a small scale may be done in Spitzbergen and the southern part of Greenland; but at present we see no likelihood of definite observations being made on the western side of Greenland further north, and in the extreme north of that continent, or on its eastern shores, either in respect to the erosion produced by its great glaciers, the effect of floe and shore-ice, or the transporting work done by the icebergs that float southwards from its shores.

Something is known of the general results, but it seems very improbable, with regard to the number and size of icebergs, and the quantity of matter they bear southwards, that anything definite is likely to be ascertained at present. The same remarks bear yet more strongly on the glacial phenomena of Victoria Land.

Seventhly. But when so much remains to be done on the Alps and on other accessible mountain-areas, such difficult points can afford to wait for the present; and we are of opinion that perhaps it is possible, after the subject has been investigated with regard to the existing glaciers of the Alps, to apply approximately the same method to the older extension of the Alpine glaciers during the last glacial period, and to invent a process by which we may be able in some degree to estimate the amount of erosive waste, and of transport of moraine matter on the surface, of the great glaciers of that epoch. Accurate surveys of the old moraines of that epoch would be essential to this end, such, for example, as that of the great moraine of Ivrea. The extent of the glacier has been shown by Gastaldi, and the area occupied by, and cubic contents of, the moraine must be estimated; and if it be possible to feel our way towards the data, attempts must be made to estimate the amount of waste of the moraine going on at the time it was deposited by the streams flowing from the end of the glacier. Numerous other considerations arise from this extended view of the question, one of which is, that perhaps it may be applied to other glaciated regions where glaciers no longer exist, such as the Vosges, the Black Forest, Wales, the north of England, Scotland, &c., thus:—Given an area such as the Alps and the Lowlands of Switzerland, covered with glacier-ice; if an approximate estimate can be formed of the amount of waste suffered by that land due to glacier-action, so under like circumstances is it possible more or less accurately to estimate the amount of erosions and other waste suffered by an equal area in such a territory as the north of Greenland at the present day.

In conclusion, any qualified person, with proper assistance and time at his disposal, could undertake the preliminary work on a single glacier; but to do what is necessary to complete it for such an area as the Alps would probably involve national scientific cooperation.

Provisional Report of a Committee consisting of Professor TAIT, Professor TYNDALL, and Dr. BALFOUR STEWART, appointed for the purpose of repeating Principal J. D. FORBES's Experiments on the Thermal Conductivity of Iron, and of extending them to other Metals. By Professor TAIT.

IN consequence of a misunderstanding, the standard thermometers ordered from the Kew Observatory did not arrive in time to be employed in the experiments hitherto made, so that the results now to be stated, besides being only *approximate*, are, for the most part, confined to a range of temperature of about 100° C. merely. Before the next meeting of the British Association the whole question will have been reexamined with far superior instruments; but with such thermometers as I had at hand (including some of those used by Principal Forbes, of which, however, I have not succeeded in obtaining the corrections determined by Welsh at Kew), results have been obtained of a character sufficiently definite for publication, though, of course, subject to (slight) future corrections and perhaps limitations.

The substances experimented on were iron, lead, and copper. Two specimens of the latter metal were employed, one of high, the other of low *electric* conductivity, the resistances of equal lengths of wires of the same gauge being about 1 to 1·64. The ratio of the *thermal* conductivities of these bars was at once found to be within 5 per cent., the same as that of their *electric* conductivities, a result certainly anticipated, but still very striking. In specific gravity and specific heat, as well as in chemical composition, mode of manufacture, and drawing, these bars of copper scarcely differ. As yet they have been treated for thermal conductivity in the hard-drawn state alone; but annealed wires of the same materials, while showing a slightly improved *electric* conductivity, maintain towards one another a ratio practically unaltered.

Two points have been observed which enable us materially to simplify the determination of thermal conductivities by Forbes's method, so long at least as moderate ranges of temperature are concerned; and we seek no greater accuracy than admits of 1 or 2 per cent. of error.

1. The *Curve of Cooling* is practically the same for all the substances I have tried (even for gas-coke), merely foreshortened or elongated in terms of a parameter, which involves the product of the specific gravity and the specific heat of the substance employed. This was, of course, to be expected, provided the radiating power of the surface be kept the same, and provided conductivity do not interfere with the results.

2. The *Curve of Statical Temperature* possesses, practically, the same property, at least for the four different bars employed. This proves that within the range of the experiments, and subject to the errors of the thermometers, the law of change of thermal conductivity with temperature is the same for lead and copper as for iron. I showed (Proc. R. S. Edin., 1867-68) that Forbes's results for iron agree closely with the statement that the conductivity is inversely as the absolute temperature, a result which is identical with Matthiessen's determinations of *electric* resistance of pure metals at different temperatures. With a view to follow up this analogy still further, I have ordered a bar of German silver, a substance whose *electric* conductivity is but little altered by temperature. The results cannot fail to be interesting.

Very simple reasoning from the (plotted) curves of *Cooling* and of *Statical Temperature* shows that, to the amount of accuracy before mentioned, the

thermal conductivities of two metals are *as the squares of the foreshortenings in their respective curves of statical temperature*. I have not considered my observations sufficiently exact (chiefly on account of the imperfection of the thermometers) to warrant my undertaking the labour of calculating the constants of empirical formulæ to represent them, but have contented myself with results derived from tracing, *liberâ manu*, curves closely representing the result of experiment.

I may mention, in concluding this provisional Report, that an air-bath has been found preferable to melted solder for heating the bars employed in the cooling experiments, and that the conductivity of copper is so much superior to that of iron that, when a source of heat above 100° C. is employed, the further ends of the 8-foot copper bars require to be kept cold by a constant stream of water. In this case the curve of statical temperature undergoes an obvious and easily allowed for modification.

Report of the Committee for the purpose of investigating the rate of Increase of Underground Temperature downwards in various Localities, of Dry Land and under Water. Drawn up by Professor EVERETT, at the request of the Committee, consisting of Sir WILLIAM THOMSON, LL.D., F.R.S., E. W. BINNEY, F.R.S., F.G.S., ARCHIBALD GEIKIE, F.R.S., F.G.S., JAMES GLAISHER, F.R.S., Rev. Dr. GRAHAM, Prof. FLEEMING JENKIN, F.R.S., Sir CHARLES LYELL, Bart., LL.D., F.R.S., J. CLERK MAXWELL, F.R.S., GEORGE MAW, F.L.S., F.G.S., Prof. PHILLIPS, LL.D., F.R.S., WILLIAM PENGELLY, F.R.S., F.G.S., Prof. RAMSAY, F.R.S., F.G.S., BALFOUR STEWART, LL.D., F.R.S., G. J. SYMONS, Prof. JAMES THOMSON, C.E., Prof. YOUNG, M.D., F.R.S.E., and Professor EVERETT, D.C.L., F.R.S.E., Secretary.

IN the last Report it was stated that several small hardy maximum thermometers suited for rough work were being constructed by Casella under the direction of the Committee. These instruments have now been in use for a year and have been found to work well.

Their construction is as follows:—A Phillips's maximum thermometer, about 10 inches long, graduated in Fahr. degrees from about 30° to 90°, is hermetically sealed within a glass tube, which is about three-quarters filled with air and one-fourth with alcohol, the thermometer being kept from touching the tube by cork rings. The thermometer thus enclosed is inserted in a copper case for protection, contact between the glass and the copper being prevented by india-rubber. The air within the hermetically sealed tube prevents the great pressure which acts upon the exterior of the tube in deep bores filled with water from being transmitted to the thermometer within. The use of the alcohol is to lessen the time required for the thermometer to come to the temperature of the surrounding medium.

The Committee would take this opportunity of stating that they will be happy to supply these instruments to any persons who will undertake to make observations of the temperature in borings.

Mr. M'Farlane (assistant to Sir W. Thomson), who furnished for the last Re-

port a series of observations taken at Blythswood bore, now furnishes observations taken with the thermometer above described at two other bores. At Kirkland Neuk bore near Blythswood, his observations were made in March and April 1868, and again in August and September of the same year. At South Balgray on the north side of the Clyde, his observations were made in July 1869. The following are the particulars of the observations.

Observations of Underground Temperature at Kirkland Neuk Bore,
Blythswood, 1868.

Diameter of bore $2\frac{1}{2}$ inches.

Taken during March and April.			Taken during August and September.
Depth.	Temp. Fahr.		Temp. Fahr.
feet.			
60	44.67	Mar. 28.	48.0
	45.50	" 31.	
120	48.15	" 20.	48.7
	48.20	" 23.	48.65
			49.0
			49.0
180	50.20	" 18.	50.20
	50.30	" 21.	50.35
240	51.70	" 13.	51.3
			51.5
300	53.10	" 7.	52.5
			52.5
354	53.60	Apr. 2.	53.5
			53.53

This bore was originally 570 feet deep, but was filled with sediment to 354 feet from the surface. During March and April the weather was rainy, and a continual flow of water from the surface passed into the bore, escaping at some unknown depth. The temperature observed varied considerably at different times, especially towards the surface. Those here recorded were taken when the surface-flow was least, the others have been rejected from their irregularity as not trustworthy.

In August and September the weather was dry, and the surface of the water in the bore remained at a nearly constant depth of 30 feet, and the temperatures observed are much more regular.

An attempt was made to have the sediment taken out so as to render the whole depth available for observation, when an accident occurred to the iron tube protecting the upper part of the bore, and nothing further has been done.

Observations of Underground Temperature at South Balgray, west from Glasgow, north from the Clyde. Diameter of bore 3 inches.

This bore, originally 1040 feet deep, is available to a depth of 525 feet. The observations here recorded were made at the beginning of July 1869, the surface of the water being constant at $5\frac{1}{2}$ feet from that of the ground. Diameter of bore 3 inches.

Depth.	Temp.	Date.	Depth.	Temp.	Date.
feet.			feet.		
60	48.2	July 2, 1869.	60	48.22	July 6, 1869.
	48.2	" 2 "		48.20	" 9 "

1869.

N

Depth. feet.	Temp.	Date.	Depth. feet.	Temp.	Date.
120	49°5	July 2, 1869.	360	55°30	July 9, 1869.
	49°5	" 2 "		55°45	" 13 "
	49°60	" 5 "		55°33	" 13 "
	49°65	" 5 "		55°35	" 13 "
	49°52	" 6 "			
	49°60	" 9 "	390	56°11	" 9 "
	49°60	" 9 "		56°09	" 9 "
				56°13	" 13 "
180	51°0	" 2 "			
	51°0	" 2 "	420	56°9	" 2 "
	51°21	" 5 "		57°30	" 5 "
	51°20	" 5 "		57°20	" 5 "
	51°21	" 6 "		57°10	" 6 "
				57°09	" 6 "
240	52°7 } ?	" 2 "		57°18	" 9 "
	52°7 } ?	" 2 "		57°20	" 9 "
	52°90	" 5 "			
	52°75 ?	" 5 "	450	57°80 ?	" 9 "
	52°91	" 9 "		58°10	" 9 "
	52°90	" 9 "		58°10	" 9 "
	52°90	" 13 "		58°32	" 13 "
	52°95	" 13 "		58°00	" 13 "
300	53°9	" 2 "	480	58°7	" 2 "
	53°8	" 2 "		58°72	" 5 "
	53°86	" 5 "		58°70	" 6 "
	53°92	" 5 "		58°70	" 6 "
	53°90	" 6 "			
	53°90	" 9 "	488	59°05	" 9 "
	53°90	" 9 "		59°00	" 9 "
360	55°7 ?	" 2 "	525	59°3	" 2 "
	55°40	" 5 "		59°6	" 2 "
	55°36	" 5 "		59°9 ?	" 5 "
	55°39	" 6 "		59°40	" 6 "
	55°31	" 9 "		59°40	" 6 "
				59°45	" 9 "

In regard to these observations, I have to remark that the thermometer had to be drawn up with great caution, as I found that the thermometer case, or a knot on the cord, meeting with a slight obstruction from rugged parts of the bore, produced a sufficient shock to cause the detached portion of the mercury to sink, which rendered the observation useless. The discrepancies in some of the observations marked (?) may be due to this cause. In several cases, when the shock was distinctly felt, I found the reading very low, and at once rejected it.

The mode of procedure was as follows:—the readings were taken generally at intervals of 60 feet (10 fathoms). For the smaller depths ice water was used to set the thermometer below the temperature of the locality to be tested, and on being brought to the surface, it was put into the water while taking the reading for considerable depths; this was unnecessary, as its passage through the colder upper strata served the purpose sufficiently. Frequently two observations were taken at one depth in succession, but never more, before proceeding to the next greater; and in no case was a reading taken at any depth after one had been made at a lower on the same day.

Between the depths 390 feet and 450 feet there is continuous shale, and I thought it might be interesting to have the temperature of both these localities.

At the depth of 488 feet commences a bed of greenstone about 140 feet thick, but the sediment prevented me from getting more than 37 feet into this bed.

As it would be interesting to get through the greenstone, I am at present making inquiries as to the expense of having the mud pumped out.

The following is an account of the strata penetrated by this bore, together with an abstract of the foregoing results :—

July 1869. South Balgray Bore.

Depth.	Nature of strata.	Number of layers.	Thickness	Temperature.	Difference.	Difference per foot.
ft.			ft. in.	°	°	°
60	Surface-soil	1	1 0	48.20	1.36	0.0227
	Sandy clay	1	3 6			
	Dark fakes	1	2 6			
	Grey fakes	2	18 9			
	Dark blaes	8	22 6½			
	Sandstone	1	10 0			
	Coal	1	1 0			
120	Ironstone	4	0 9	49.56	1.56	0.0260
		19	60 0½			
	Dark fakes	2	6 9			
	Dark blaes	9	29 7			
	Sandstone	2	17 6			
	Coal	1	3			
	Ironstone	6	5 11			
180		20	60 0	51.12	1.72	0.0287
	Dark fakes	4	9 6			
	Grey fakes	3	16 3			
	Dark blaes	3	8 5½			
	Light blaes	1	1 2			
	Sandstone	3	22 2			
	Coal	2	1 5			
240	Ironstone	3	1 0½	52.84	1.04	0.0173
		19	60 0			
	Grey fakes	1	3 6			
	Dark blaes	10	38 9			
	Sandstone	1	10 8			
	Ironstone	8	7 1			
		20	60 0			
300	Dark fakes	2	17 3	53.88		
	Grey fakes	2	12 10			
	Dark blaes	1	4 0			
	Sandstone	1	25 8			
	Ironstone	1	0 3			
		7	60 0			

July 1869. South Balgray Bore (*continued*).

Depth.	Nature of strata.	Number of layers.	Thickness.	Temperature.	Difference.	Difference per foot.
ft.			ft. in.		°	°
360	Dark fakes	3	11 4½	53.88	1.52	0.0253
	Fakey sandstone	2	25 7			
	Dark blaes	8	17 6½			
	Ironstone	7	5 6			
		20	60 0			
390	Dark fakes	3	19 8½	55.40	0.71	0.0237
	Dark blaes	1	6 4½			
	Sandstone	3	3 11			
		7	30 0			
420	Dark blaes	..	30 0	57.14	1.03	0.0343
450	Dark blaes	..	30 0	58.13	0.99	0.0330
	Dark blaes ...	..	6 4½		0.57	0.0190
	Dark limestone.	1	3 1			
	Light do. hard	4	7 0			
	Limey fakes ..	4	13 1			
480	Parting	1	0 1	58.70	0.82	0.0182
	Fakey limestone	1	0 4½			
		11	30 0			
	Fakey limestone	..	10 10½			
	Greenstone	1	34 1½			
525		1	45 0	59.52		

Difference of temperature for 465 feet . 11°32,

Mean difference of temperature per foot 0°0244,

being at the rate of 1° for 41 feet. It will be remarked that the shale, which extends from 390 feet to 450 feet, shows a more rapid increase of temperature, and therefore smaller conductivity than the other strata*.

The following is an account of the strata penetrated by the Blythswood bore (No. 1), together with an abstract of the temperatures observed in it. The particulars of the observations of temperature were given in last year's Report.

* As regards the relation between rate of increase of temperature downwards and thermal conductivity, it is to be borne in mind that in comparing different parts of one bore these quantities are generally in inverse proportion to each other; but this rule does not apply to the comparison of two bores in different localities. See Mr. Hopkins's paper, Phil. Trans. vol. cxlvii.

1867-68. Blythswood Bore, No. 1.

Depth.	Nature of strata.	Number of layers.	Thickness.	Temperature.	Difference.	Difference per foot.
ft.			ft. in.			
60	Surface-soil	1	1 6	°	°	°
	Till with stones.	1	46 6			
	Dark till	1	12 0			
		3	60 0	47.95		
	Dark till	..	11 0			
	Fakes	2	6 3			
	Dark blaes	10	12 4½		1.27	.0212
	Blaes and fakes .	4	12 6			
	Sandstone	6	15 7½			
	Coal	3	1 8			
120	Ironstone	3	0 7			
		28	60 0	49.22		
	Sandstone fakes.	8	21 2½			
	Blaes	7	18 1½			
	Sandstone	4	18 3		1.28	.0213
	Coal	2	1 6½			
	Ironstone	4	0 10½			
		25	60 0	50.50		
	Sandstone fakes.	7	33 2½			
	Sandstone	5	10 4		1.08	.0180
180	Blaes	9	15 8½			
	Ironstone	4	0 9			
		25	60 0	51.58		
	Sandstone fakes.	2	10 0½			
	Sandstone	2	8 6½		1.18	.0197
	Dark blaes	12	36 11			
	Ironstone	11	4 5¾			
		27	59 11¾	52.76		
	Sandstone	2	18 2			
	Dark blaes	4	27 9½		.93	.0198
240	Fakes	1	0 3			
	Ironstone	2	0 9½			
		9	47 0	53.69		
300						
347						

Our attempts to obtain the journal of the Kirkland Neuk bore, showing the strata penetrated by it, have not as yet been successful. The mean rate

of increase, calculated from the observations in August and September, is $0^{\circ}\cdot0187$ per foot, or 1° for 53·5 feet.

This is the bore which was referred to in the following passage of last year's Report.

"It has been selected because the mining engineer states in his report that the coal has been very much burned or charred, showing the effects of heat; and it becomes an interesting question, Are there any remains of that heat that charred the coal in ancient times, or has it passed off so long ago that the strata are now not sensibly warmer on account of it?"

The observations seem to establish the latter alternative, this bore being rather colder than its neighbour, the Blythswood No. 1.

Mr. G. J. Symons, Member of the Committee, has furnished the following account of observations taken by him to the depth of 1100 feet in an artesian boring at Kentish Town:—

"Observations have been made during a considerable length of time, and with every precaution and care, through the London Clay, Thanet Sands, Chalk, Upper Greensand, and Gault, in the vicinity of the metropolis, under the following circumstances.

"There exists in the northern suburbs of London, between Kentish Town and Highgate, a remarkably large well, 8 feet in diameter and 540 feet deep, lined throughout with the finest brickwork, and reaching 214 feet deep into the Chalk. This well was the property of a Company whose Act of Parliament bore date 35th Henry VIII. (A.D. 1544), and afforded a supply of water to the surrounding neighbourhood until, in 1852, when, under the joint influence of the Board of Health, who objected to hard water, of increasing demand and decreasing quantity, the Company decided on seeking a fresh supply. It was represented to them as most probable that by sinking a bore-tube to a depth of about 1000 feet, the Lower Greensand would be tapped, and an abundant supply of excellent water obtained. The then existing well being more than half the entire depth required, it was decided to bore from its bottom, and thus save half the cost. The boring was carried down to 1302 feet (nearly a quarter of a mile), but the Lower Greensand was absent; some unknown rocks were penetrated, and the Company, after spending on their works, well, and boring nearly £100,000, became bankrupt; the New River Company purchased the plant, but were advised not to continue the search; the buildings were sold for old materials, and the whole left in a ruinous condition.

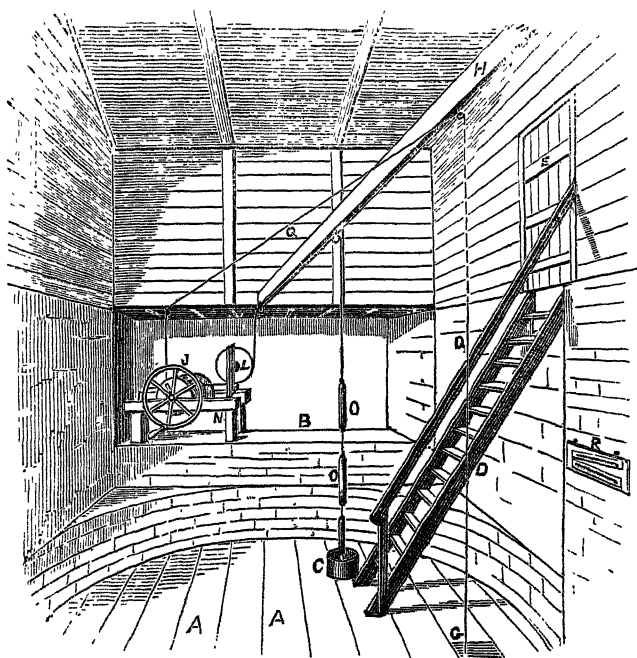
"I consulted other members of this Committee as to the expediency of obtaining from the New River Comp. permission to experiment on this bore, and consent having (through the courtesy of Mr. Muir, the Company's engineer) been obtained, it was decided that observations should be forthwith commenced.

"Owing to the ruinous condition of the top of the well, and the depth of the top of the bore-tube below the ground, very considerable danger and discomfort attended the preliminary arrangements, although those very difficulties have eventually led to the detection of sources of error not previously suspected, and to exceptionally accurate results.

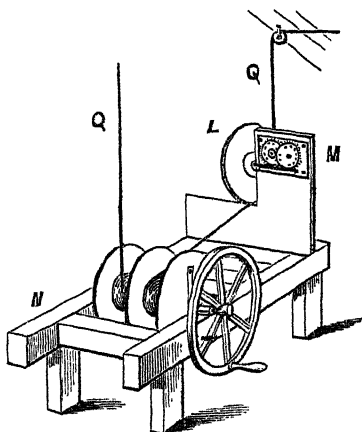
"The accompanying sketches explain pretty clearly the exact circumstances under which the observations were taken, viz. that a hut was erected over the top of the well to shut out, as far as practicable, external temperature and to protect the apparatus; that a stout floor was fixed 10 feet down the well to afford access to the tube* and safety to the observer, the top of the

* "It is scarcely necessary to say that the tube commences 9 feet below the surface of the ground, and passes down through the well."

tube only rises one foot above the floor, and is plugged with a large ball of felt to prevent external air having free communication with the tube. The exact limits of the various strata are also shown, together with the *constant*



A, floor, 10 feet below surface of ground. B, brick-ledge. C, bore-tube, fitting tightly in floor. D, steps leading to entrance door E. G, opening into well, with trap-door. H, beam supporting pulleys, over which pass two cords Q Q, one leading to tube and the other to well. J, windlass, separately represented in second figure. L, registering-apparatus, with dials M, indicating amount of cord paid out. N, stand of windlass, fixed to brick-work B. R, thermometers for temperature of observing room. O O, thermometers for underground temperature.



depth at which water stands in the tube: this constancy is worth notice; for whereas in most cases water-levels vary with the rainfall in the districts whence they obtain their supply, the water at Kentish Town has not varied more than six inches during the last ten months, and is very muddy. The diameter of the bore-tube is 8 inches.

Two thermometers have always been used in these observations,—one

similar to those designed for the use of the Committee by Sir Wm. Thomson, and the other an extra strong Six's thermometer, as supplied to the Admiralty by Casella. The influence of great pressure on the indications of thermometers having recently attracted considerable attention, it may be well to state that the greatest pressure to which those used at Kentish Town have been submitted is about a fifth of a ton per square inch, and this causes the Six's thermometer to rise about $0^{\circ}\cdot4$; Sir W. Thomson's thermometer being protected by an outer glass tube is entirely uninfluenced by this pressure, or even, as Professor Miller's experiments have shown, by a pressure of *two tons and a half on the square inch**. Hence it is certain that pressure has been deprived of all influence. The use of two thermometers of different constructions ensured the detection of any slipping or accidental error in the observations, but in the regular series not a single instance of the kind has occurred.

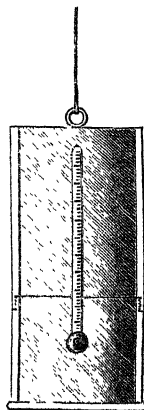
"In order to ascertain the depth of the instruments easily, accurately, and independently of any variation in the hygrometric condition of the lowering-cord, it was conducted from the windlass round a grooved wheel exactly 36 inches in circumference, to whose axle an endless screw was attached, which worked a train of divided wheels, so that the exact distance could be taken at any instant.

"It was supposed that several trustworthy observations could be obtained in the course of one day; but the following Table shows that this was not the case, and confirms the expediency, where practicable, of allowing considerable time for the instruments &c. to come to thermal equilibrium. At Kentish Town the observations on which reliance is placed have been made at intervals of not less than six days, and generally of seven. On two or three occasions, however, attempts have been made to obtain observations at short intervals, and the following are the results:—

Depth, in feet.	Time allowed.	Date.	Temperature indicated.	True temperature.	Error.
100	1 hour.	March 5.	50·1	51·0	—0·9
200	"	"	51·8	53·6	—1·8
300	"	"	56·1	56·1	0·0
400	"	"	55·0	58·1	—3·1
500	"	"	58·1	60·2	2·1
"	"	"	60·0		—0·2
"	"	"	60·2		0·0
550	"	Feb. 12.	61·0	61·0	0·0
600	"	March 5.	58·0	61·2	—3·2
"	"	"	58·2		—3·0
700	"	"	62·5		—0·3
"	"	"	62·6	62·8	—0·2
710	Half-hour.	"	62·8		—0·1
"	"	"	62·9		0·0
750	20 minutes.	Feb. 19.	63·0	63·4	—0·4

* "Professor W. A. Miller's experiments were made with an hydraulic press, and are described in the Roy. Soc. Proceedings for June 17, 1869 (No. 113). Several thermometers

"It is well known that in the solid crust of the earth the influence of seasons penetrates but a slight depth, say 60 feet; but it occurred to me that this might not hold good in the case of such an opening as the Kentish Town well. I therefore decided on commencing my observations at midwinter, continuing them regularly to midsummer, and then repeating every observation; those at each depth will therefore have been taken twice at exactly opposite seasons, and at intervals of six months. The necessity for this extreme care did not appear obvious at first, and it seemed as if the various precautions against the ingress of atmospheric temperatures had rendered it superfluous; but during recent hot periods its desirability has become abundantly manifest: the temperature at a depth of 50 feet was $49^{\circ}2$ in January and $54^{\circ}1$ in July; that at 100 feet was 51° in January and $54^{\circ}3$ in July; at 150 feet $52^{\circ}1$ in January and $54^{\circ}7$ in July. It is therefore evident that under the circumstances existing at Kentish Town, it is more easy to determine accurately the temperature at great depths than at the lesser ones. It is certain that but for the precautions taken, and the unusual mildness of the winter, the temperature at 50 feet would have been much below $49^{\circ}2$. Whence it further appears that though a single observation at depths below 200 feet will probably give accurately the true temperature at any selected depth, yet in shafts and bores similarly circumstanced to that now under notice, very discordant results may be obtained at lesser depths. Moreover, it is obviously impossible, by any but long-continued observations, to determine accurately the surface-temperature of the ground, or the equivalent of a depth of 0 feet; it may therefore be expedient, for the purpose of completing the series, to assume that the mean temperature of the surface of the soil at Kentish Town, 187 feet above mean sea-level, is identical with that of the air at Greenwich (49°) at 159 feet above the sea, and it is satisfactory to find that the observations hitherto made agree perfectly with this hypothesis. Although, as we have already stated, the experiments are by no means concluded, it may be convenient to tabulate the results hitherto obtained. Being impressed with the high importance of accurate knowledge of the rate and amount of seasonal change in the shaft, Mr. Symons designed, and Mr. Casella (aided in part by Messrs. Silver & Co.) constructed, a very delicate thermometer, which was cased 5 inches thick in felt and non-conducting materials, and enclosed in an ebonite box, as in the annexed section; the non-conducting powers of this instrument were such that on one occasion it was raised into the observing-room showing a temperature of $51^{\circ}14$, and after being in a temperature of 60° for thirty-five minutes it had only risen $0^{\circ}02$. By this means it was therefore possible to bring up the exact temperature of any required depth, uninfluenced by the warmer or colder strata through which it might have to pass. It was regularly observed for some time during the present spring, and the following readings obtained:—



were experimented on. Sir W. Thomson's is that which is designated 'No. 9645. A mercurial maximum thermometer, on Professor Phillips's plan, enclosed in a strong outer tube containing a little spirit of wine, and hermetically sealed.' "

“Temperature by Insulated Thermometer 100 feet below Surface.

				Increase per diem.	
				°	
“1869, April 3		51.21		0.021	} Increase, April 3 to June 11, 0.89 or 0.013 per diem.
” ” 12	....	51.40	....	0.008	
” ” 17	....	51.44	....	0.011	
” ” 24	....	51.52	....	0.003	
” ” 30	....	51.54	....	0.006	
” May 7	....	51.58	....	0.024	
” ” 14	....	51.85	....	0.021	
” ” 21	....	52.00	....	0.011	
” ” 28	....	51.92	....	-0.003	
” June 4	....	51.94	....	+0.025	
” ” 11		52.10			

“The main results of the experiments in the bore-tube are shown in the following Table:—

“Abstract of Results obtained at Kentish Town Well, Jan. 1 to June 30, 1869.

Depth.	Date of observation.	Observed temperature.	Difference for 50 feet.	Rate of increase, in degrees per foot.	Temperature in observing-room.		Depth of rain.	Depth to surface of water in tube.
					Max.	Min.		
ft.			°				in.	ft. in.
50	Jan. 8.	49.2	1.8	.036	46.8	38.2	1.06	
100	” 15.	51.0	1.1	.022	49.2	39.5	.20	
150	” 22.	52.1	1.5	.030	46.8	36.0	.22	210 0
200	” 29.	53.6	2.4	.048	43.0	31.8	.64	
250	Feb. 5.	56.0	0.1	.002	48.4	39.5	.83	208 6 (a)
300	” 12.	56.1	0.0	.000	49.4	42.3	.89	210 6
350	” 19.	56.1	2.0	.040	48.2	39.2	.38	
400	” 26.	58.1	1.0	.020	46.5	36.8	.67	209 6
450	Mar. 5.	59.1	1.1	.022	46.5	35.2	.59	210 0 (b)
500	” 12.	60.2	0.8	.016	45.8	35.2	.10	
550	” 19.	61.0	0.2	.004	44.0	34.8	.15	
600	” 23.	61.2	0.2	.004	44.5	37.6	.95	
650	” 27.	61.4	1.4	.028	43.0	34.9	.05	219 0 (c)
700	April 3.	62.8	0.6	.012	43.6	36.0	.22	211 0
750	” 12.	63.4	0.8	.016	54.0	37.3	.19	
800	” 17.	64.2	0.8	.016	54.4	46.2	.38	209 0
850	” 24.	65.0	0.8	.016	52.4	40.8	.53	
900	” 30.	65.8	0.9	.018	56.2	40.6	.01	210 0
950	May 7.	66.7	1.1	.022	53.8	43.5	1.00	
1000	” 14.	67.8	1.2	.024	54.2	45.4	.47	210 6
1050	” 21.	69.0	...	...	55.2	44.2	.47	210 6 (d)
1070	” 24.	69.3	...	...				
1085*	” 28.	69.6	...	...	58.0	47.2	.75	210 6
1085*	June 4.	69.8	...	...	56.0	43.0	.58	
1100*	” 11.	69.7	1.0	.014	61.9	48.5	.01	210 6
1100*	” 14.	70.0		.020				

REMARKS.

“(a) First observation in the water.

“(b) Water becomes muddy.

“(c) This water-measurement seems erroneous.

“(d) On attempting to lower the thermometers to 1100 feet, found the mud supported them, and the cord became slack. The observations to which an asterisk is attached were obtained by leaving the cord so slack as to allow the thermometers to bury themselves in the mud; but there is much risk in attempting to withdraw them.”

“ Assuming 49° as the surface-temperature, and adopting 70° as the temperature at 1100 feet, we find, for the mean rate of increase downwards, $\cdot 0191^{\circ}$ per foot, or 1° for 52·4 feet.

“ Comparing the first observation in the water (56°) with the temperature at the bottom (70°), the mean rate of increase comes out $\cdot 0165$, or 1° for 60·6 feet.

“ During the remainder of the present year the repetition of the observations will be continued, and it is hoped the influence of seasonal changes will be measured and eliminated. In conclusion, we have to acknowledge the liberality of the New River Company in allowing Mr. Symons unreserved access to their grounds, and permission to erect the necessary apparatus, which has been efficiently protected by their servants.”

I desire to say, in reference to the foregoing Report, that the length of time which Mr. Symons found it necessary to interpose between his observations is a peculiar circumstance of which I can at present offer no sufficient explanation, and I cannot help thinking that it might be obviated by some modification of the arrangements. Mr. M'Farlane, in three different bores, has found 15 minutes amply sufficient to give the correct temperature. Can the difference be owing to the greater size and smoothness of the bore in this instance offering less resistance to vertical currents?

As regards the first 210 feet, being the portion occupied by air, it is not surprising that the influence of season should here be perceptible, seeing that the well is 8 feet in diameter. The temperature of the air in an opening of this size, *even for the average of the year*, cannot be taken to represent that of the solid earth at the same depth, but will doubtless be found to be intermediate between the latter and the mean temperature of the external air.

The Rev. Dr. Graham (Member of the Committee) has taken observations in a bore at Logie Works, near Dundee, through the kindness of the proprietors, Messrs. Edwards, from whom he received much assistance. The bore was available to the depth of 640 feet, and was described, before the observations, as being filled nearly to the surface with water, in which there was no perceptible motion. Much difficulty was experienced from the shaking down of the detached column of mercury in the thermometer; but this was at length obviated by fixing the thermometer horizontally in a hollow cup in a piece of hard wood, which had a hinged glass cover to permit of reading the indications, provision being made for the free circulation of the water, and a weight being attached to the bottom to act as sinker. The temperatures observed were exceedingly anomalous, being about 10° greater at 100 feet than at 50 feet, then increasing to the depth of about 400 feet, and afterwards decreasing to the bottom. Dr. Graham states that he and his assistant observers were convinced that the water which filled the bore was obtained at the depth of about 170 feet, and that while one portion rose to the surface, another and smaller flowed downwards and escaped through the lower strata.

Mr. John Hunter, Assistant to the Professor of Chemistry, Queen's College, Belfast, has taken a few observations in two shafts, sunk with a view to salt-mining, at high ground near Carrickfergus. In both of them the water stood only to the depth of a few feet. It was found that the temperature of the air within the shafts increased downwards, at any one time, with tolerable uniformity, but varied greatly with the weather. The shafts were kept constantly closed by boarded covers, except during the actual process of observing. The temperature of the water at the bottom, which is as-

sumed to represent pretty accurately the temperature of the soil at the same depth, was $62^{\circ}\cdot4$ in Dunderue shaft at the depth of 570 feet (observed November 7, 1868), and 66° in Mr. Dalway's new shaft at the depth of 770 feet (observed November 14, 1868). Assuming 48° as the mean surface-temperature, the increase of temperature downwards would be at the rates of 1° in 40 feet and 1° in 43 feet respectively. The soil in both cases was yellow clay.

Mr. David Burns, of H.M. Geological Survey, now stationed at Allendale near Carlisle, has taken observations in that neighbourhood, which he thus describes:—"The first shaft I tried is over 50 fathoms in depth, and is about half full of water. It is situated on the summit of a ridge a few yards distant from a fault of some 900 feet throw. The flow, or rather change, of water in it, from these or other causes, is considerable, as is shown by the temperature. The result of my observations may be put thus:—

"After a period of drought—

feet.	Temperature $47^{\circ}\cdot5$
" Depth 160	
" 200	" 47
" 250	" $47\cdot7$
" 300	" $47\cdot7$

"The minimum temperature is at 200 feet. This reading may be relied on, as I repeated the observation to make sure of it. Perhaps at this level lies the chief feeder of water.

"Shortly after heavy rains—

feet.	Temperature 47°
" Depth 160	
" 200	" $47\cdot5$
" 250	" $47\cdot3$
" 300	" $47\cdot3$ "

Mr. Burns goes on to relate his unsuccessful attempts to take observations in two other shafts, which turned out to be closed, probably by platforms, at a depth of several feet below the surface of the water.

In concluding this Report, I would beg to direct attention to a valuable summary of observations of underground temperature at great depths contributed by Mr. Hull to the 'Quarterly Journal of Science' for January 1868, from which the following Table of results has been condensed:—

	Depth, in feet.	Temperature at bottom, in degrees Fahr.	Average rate of increase. feet.
Puits de Grenelle, near Paris	1794·6	81·95	$\frac{1}{2}$ for 59
Boring at Neu Salzwark, Westphalia .	2281	91·04	1 " 54·68
Boring near Geneva . . . . .	....	....	1 " 55
Boring at Mendorff, Luxemburg . . .	2394	....	1 " 57
Monkwearmouth Colliery	1499	....	1 " 60
Rose Bridge Colliery, near Wigan ..	1800	80	1 " 58·31
Astley Pit, Dukensfield, Cheshire . .	2040	75·5	·1 " 83·2

Mr. Hull strongly insists on the necessity of observations at greater depths. He gives reasons for maintaining that, at depths exceeding 2000

feet, no water would be found in ordinary Coal-measure strata, and offers a recommendation in the following terms:—

“After much consideration, the plan which we venture to recommend, in case of experiments being undertaken by the British Association, or any other scientific society, would be, not to commence at the surface, but at the bottom of a coal-mine, of not less depth than 600 yards.

“There are several collieries, particularly in Lancashire and Cheshire, sufficiently deep for the purpose. It would be an easy matter to excavate a chamber in the coal and its roof, where the borings might be carried on. The chamber ought to be a short distance from the bottom of one of the shafts, and out of the way of mining-operations. As the process of boring progressed, observations should be taken at every 10 yards, and at every change of strata, from sandstone to shale or coal. The boring might be carried down at least to a total depth of 1000 yards from the surface, and having been completed under proper supervision, could not fail to give results of value to science. It is also probable that a proprietor of some colliery of the required depth would willingly afford the facilities for carrying on the experiment, for the sake of the information he would derive regarding the minerals underlying the coal-seam then being worked.”

With respect to this recommendation, I may say, in the name of the Committee, that they consider it very valuable, and would gladly avail themselves of any opportunity of carrying it out, so far as the funds at their disposal permit.

Fifth Report of the Committee for Exploring Kent's Cavern, Devonshire.

The Committee consisting of Sir CHARLES LYELL, Bart., F.R.S., Professor PHILLIPS, F.R.S., Sir JOHN LUBBOCK, Bart., F.R.S., JOHN EVANS, F.R.S., E. VIVIAN, GEORGE BUSK, F.R.S., WILLIAM BOYD DAWKINS, F.R.S., and WILLIAM PENGELLY, F.R.S. (Reporter).

BEFORE commencing the Report of their researches during the last twelve months, the Committee beg to call attention to a few facts connected with branches of the Cavern explored in previous years.

In their Third Report, presented to the Association at Dundee in 1867, they stated that in a part of that branch of the Cavern termed the “Vestibule,” there was *beneath* the Stalagmitic Floor, and generally in direct contact with its nether surface, a layer of black soil, known as the “Black Band,” which varied from 2 to 6 inches in thickness, covered an area of about 100 square feet, and at its nearest approach was 32 feet from the northern entrance of the Cavern. They also stated that this Black Band contained a large amount of charcoal, and that in it had been found 366 flint implements, flakes, cores, and chips; a bone harpoon or fish-spear, and a bone awl; and numerous bones and teeth of extinct and recent animals, some of which were partially charred. They further remarked that were they to speculate respecting the probable interpretation of the Black Band—bearing in mind its very limited area, its position near one of the entrances of the Cavern and within the influence of the light entering thereby, its numerous bits of charcoal and of burnt bones, its bone tools and its very abundant, keen-edged, unworn, and brittle chips and flakes of whitened flint,—they might be tempted to conclude that they had not only identified the Cavern as the home of an

early British family, but the Vestibule as the particular apartment where they enjoyed the pleasures of their own fireside, cooked and ate their meals, and fashioned flint nodules and bones into implements for war, for the chase, and for domestic use*.

To the foregoing description of the Black Band and its locality, it may be added that, even during very wet seasons, that part of the Cavern is very little exposed to drip from the roof.

It may not be out of place to state here that, in order to ascertain to what extent the light penetrating the entrance of the Cavern was available, one of the Superintendents of the exploration placed himself near the centre of the Black-Band area, and found that without any artificial light he could distinctly see to write a letter and to read ordinary print.

But whilst the Committee have seen no reason to abandon or to modify their interpretation of the Black Band, and whilst it has been generally accepted by those who by personal inspection have made themselves familiar with the phenomena of the Cavern, they have found that by one very able and experienced observer it has been regarded with some amount of scepticism, on the ground that the smoke of a fire in the Cavern would either suffocate or expel the inhabitants; that, in short, the interpretation was inconsistent, since it supposed the Cavern to have been inhabited under conditions which would render it uninhabitable.

To test the force of this objection, six large faggots of wood were piled in a heap and set on fire, as nearly as possible on the centre of the area which the Black Band had occupied. The fire burnt brilliantly and threw out large tongues of flame, which licked the roof, whilst a party of five persons, without the least inconvenience from smoke or any other cause, sat on the rocky sides of the Cavern and watched the experiment. They were unanimous in the opinion that the objection that was thus put on its trial was utterly invalid. It may be mentioned, too, that the temperature of the Cavern is permanent, and stands by night and by day, in summer and in winter, at about 52° Fahr., or half a degree above the mean annual temperature of the district in which Kent's Hole is situated. Hence it may be concluded that, unless the Black Band represents a period when the mean temperature of South Devon was considerably below that which at present obtains, large fires would not have been needed. Artificial heat would have been required, not to make the Cavern tenable, but perhaps for culinary purposes only.

Before quitting this subject, it may be stated that the smoke drifted towards the interior of the Cave, and that one of the party, who from time to time passed all round the fire and to various distances from it, reported that in the narrower adjacent ramifications it was oppressive.

Soon after the Meeting at Norwich in 1868, Mr. Boyd Dawkins, a member of the Committee, intimated his intention of visiting Torquay for the purpose of examining and naming the remains of the Cave-animals which had been collected during the exploration. It has been stated in previous Reports that, from the beginning, a separate box has been appropriated to the specimens found in each distinct "yard" of deposit, that is, in each parallelopiped of Cave-earth a yard in length and a foot in breadth and in depth, that with each set of specimens was packed a numbered label, and that the Secretary recorded in his daily Journal full information respecting the precise position of the objects thus numerically defined, as well as the date on which they were exhumed. It may be added that, as soon as the specimens

* Report Brit. Assoc. 1867, p. 32.

were cleaned and packed, the boxes were stowed away in a room set apart for them, the door was locked, and the Secretary never parted with the key. It is obvious that the number of boxes of specimens waiting for examination was equal to the number of "yards" in which fossils have been found. On the 31st of December, 1868, this number was 3948; and though it is true that some of the boxes contained no more than a single bone, it is also true that in many of them there were upwards of a hundred; hence it will be seen that the task Mr. Dawkins had before him possessed Herculean dimensions. When he began his examination, there must have been in store for him more than 50,000 bones; and though many of them were unidentifiable chips merely, every one had to pass under review.

In order that this gigantic labour might be somewhat facilitated, the Secretary commenced to unpack each box, and to write on every specimen it contained the number written on the accompanying label. While thus engaged, on the 24th of September, 1868, with the box labelled 1847, he found amongst its contents what appeared at first to be merely a very small bone, the greater part of which was covered with a film of stalagmite. On being touched, the investment fell off (a very common occurrence in the case of similar specimens after having been washed and dried), and the object proved to be a portion of a bone needle, having its point broken off but retaining its perfect and well-formed eye. This part had been concealed and, happily, protected by the calcareous covering. The remnant is about $\cdot 85$ inch long and is slightly taper. Its section at right angles to its longest axis is subelliptical, resembling that of a modern bodkin rather than that of a needle. Its greater diameter at the larger end is about $\cdot 075$ inch, and at the smaller $\cdot 05$ inch; hence, assuming it to have been symmetrical in form and to have terminated in a point, its original length must have been $2\cdot 55$ inches. There are numerous fine longitudinal striæ on its surface, suggesting that it had been scraped into form. The Secretary's daily journal shows that it was exhumed on the 4th of December, 1866, and that it belonged to the Black Band *beneath* the Stalagmitic Floor.

Since its discovery it has unfortunately been broken, the line of fracture passing through the eye. Before the accident it had been seen by several members of the Committee and by many other persons. The parts have been very carefully and firmly reunited. The eye was capable of carrying a thread about three-eighths of an inch in diameter, or about the thickness of fine twine.

On November 26th, 1868, while still engaged in preparing the specimens for Mr. Boyd Dawkins, the Secretary had the good fortune to detect, under precisely similar conditions, in the box labelled 2206, a bone "harpoon" or fish-spear barbed on one side only. When dug out of the deposit it was in two pieces, one of which was almost, and the other completely, encrusted with stalagmite. Indeed the latter was regarded as a pipe of stalactite, and as such was preserved. It is recorded in the Secretary's journal that it was disinterred on the 7th of March, 1867, in the Vestibule, in the first or uppermost foot-level of Cave-earth, beneath the Black Band, which was 4 inches thick, and which was covered with a Stalagmitic Floor varying from 12 to 20 inches in thickness, and that this, again, was overlaid with Black Mould containing pre-Roman and Romano-British objects.

The fact that remains of the extinct Cave-bear, Hyæna, and Rhinoceros have been met with not only in the Stalagmitic Floor just mentioned, but quite at its upper surface, must be borne in mind when attempting to form an estimate of the chronology of the needle and "harpoon" just described.

Besides the foregoing, there was found during the preparatory examination, in the box numbered 2067, a canine of a Badger, the fang of which had been cut or otherwise reduced to a wedge-like form, and perforated obliquely as if for the purpose of being strung. It was exhumed on February 4th, 1867, in the "Vestibule" in the second foot-level of Cave-earth, which is believed to have been intact; but as the overlying Stalagmite had been broken up and removed by the earlier explorers, the Superintendents do not feel perfect confidence in the trustworthiness of its position.

The foregoing are the only objects of peculiar interest which have been recently detected among the specimens collected by the Committee, prior to the last Meeting of the Association, from the deposits beneath the Stalagmitic Floor.

There have been found, however, two noteworthy objects, among those which had been met with in the Black Mould overlying the Stalagmite, and which, therefore, can have no pretensions to great antiquity. The first is a bone needle, by no means so elegantly designed or so highly finished as that just described. Its proportions also are such as to secure for it great strength, and to enable it to carry a thread or cord of considerable size.

The second object is a ring, apparently of Kimmeridge Coal, or some kindred substance. The diameter of the greater circle is upwards of an inch, and of the inner one about half an inch. The annulus is about .2 inch thick at its inner edge, and both surfaces are uniformly bevelled to a line at the outer edge. Its breadth is not uniform, as the circles are not concentric.

Researches during the year 1868-69.—During the year which has elapsed since the Meeting at Norwich in 1868, the Committee have, with very slight modifications to be noticed hereafter, conducted the excavation on the method described in detail in their First Report (Birmingham, 1865); the Superintendents have continued their daily visits to the Cavern; the Secretary has recorded in his daily journal such facts as have presented themselves; monthly Reports have been regularly forwarded to the Chairman of the Committee; the workmen have continued to be interested in their work, which they have performed with great zeal and integrity; the interest felt by the general public in the progress of the investigation has suffered no diminution; and the arrangements for the admission of visitors, which in previous years worked so satisfactorily for all parties, have in all cases been carried out.

Since the last Report was sent in, the Superintendents have had the pleasure of showing the Cavern and explaining the operations to the Queen of the Netherlands and her suite, the Right Honourable Sir George Grey, the Right Honourable John Bright, and several Members of the British Association, including Sir W. Tite, Mr. G. Griffith (Assistant General Secretary), Professor Tyndall, Mr. W. A. Sanford, Mr. W. Froude, Mr. J. E. Lee, Mr. S. R. Pattison, and others.

Mr. Everett, who is about to proceed to Borneo to explore some of the caverns in that island under the auspices of the Raja of Sarawak, recently spent two days (July 31st and August 2nd) in Kent's Hole, accompanied by one of the Superintendents, for the purpose of studying the operations in detail. It may be hoped that the British Association has in this way been able to render valuable aid to the Committee who have undertaken the important work of cavern exploration in the far east.

The South-west Chamber.—In the Fourth Report (1868) the Committee stated that they were occupied in excavating that portion of the Cavern termed the "South-west Chamber," which, so far as was then known, was the last or most south-westerly branch of the Eastern Series of Chambers and Galleries.

They added that the portion of the Chamber which they had reached was completely closed with an enormous accumulation of Stalagmite, so that it was not possible to form a correct estimate of the size of the apartment, that it was probably much larger than was then supposed, that the only known communication between the Eastern and the Western Divisions of the Cavern was the Vestibule at its opposite or north-eastern end, and that the Superintendents inclined to the opinion that a passage would be found opening out of the South-west Chamber, which would form a second channel of communication between the two Divisions. Respecting the deposits, the Fourth Report stated that, in the eastern part of the Chamber, they were:—first, or uppermost, Stalagmitic Floor, commonly of granular structure; second, the ordinary Cave-earth, with flint implements and the usual Cave-mammals; third, an Old Floor of Stalagmite of great thickness, and of a peculiar crystalline structure; fourth, or lowest, a Rock-like Breccia, in which fragments of grit, not derivable from the Cavern hill, were abundant, and which, though replete with remains of the Cave-bear, had neither bones nor any other indications of Hyæna, Rhinoceros, or other prevalent Cave-species. It was added that in proceeding westward the Cave-earth had thinned out and entirely disappeared, so that the two Stalagmites, between which was its proper place, rested one immediately on the other.

Soon after that Report was presented, the Committee found that a few feet beyond the point where they had lost the Cave-earth, it once more appeared in the section, occupying its accustomed position between the Stalagmites, resting on the Old crystalline mass, and overlaid with that which is granular and comparatively modern. It proved to be merely an insulated patch in contact with the northern wall of the Chamber, along which it extended for a distance of 11 feet. Its maximum breadth was $6\frac{1}{2}$ feet, and depth 32 inches. No sooner did it enter the section than it brought with it the characteristic flint and chert implements, teeth of hyæna, mammoth, and fox, and gnawed bones.

Three of the implements deserve more than a brief mention, as they are very fine specimens, belong to different types, and can scarcely be said to be represented by any previously met with in the Cavern.

The first (No. $\frac{1}{3912}$ *) is of a dull light grey colour on the surface, but of an undecided black within. In form it is a trapezoid closely approaching a rectangle, but having the angles somewhat rounded off. It is about 4 inches in length, $2\frac{1}{2}$ inches in breadth, and $\cdot 8$ of an inch in greatest thickness. It is worked to an edge along the entire margin, and has apparently seen some service as a scraper. With it were found a portion of a chert implement, a molar of bear, molar of hyæna, four other teeth, a gnawed bone, and several small fragments of bone.

The second implement (No. 3918) is a beautifully white flint of porcellaneous aspect. Its form is not easy to describe, but it may perhaps be said to be rudely subovoid. Its extreme length is about 3·9 inches, breadth 2·5, and depth $\cdot 7$ inch. It is flat on one face, and from a point near the centre of the other side is unequally fined off to an edge all round the perimeter.

The third (No. 3922) is of the same kind of flint as the second. Every part of its surface is elaborately chipped. It is flat on one side, uniformly rounded on the other, and worked to an edge all round its circumference. It may be described as a canoe-shaped implement, or a long, narrow, pointed,

* 3912, the denominator, is the number of the box or series of specimens; 1, the numerator, is the number of the specimen in the series; and so on in other cases.—W. P.
1869. o

nearly symmetrical semiellipsoid, the principal diameters of which are 4·7 inches, 1·3 inch, and ·6 inch. There were found with it several teeth of hyæna, bear, and fox, and a small quartz crystal.

The Cave-earth in which these specimens were found was completely sealed up with the ordinary overlying floor of stalagmite, which, though never quite a foot thick, was at its upper surface almost everywhere in contact with the limestone ceiling of the Chamber, and was nowhere separated from it by an interspace of more than 3 or 4 inches.

The same sections, continued across the Chamber towards its southern wall, successively and uniformly showed that, beyond the patch just mentioned, they contained no Cave-earth, but were made up of one undivided huge accumulation of Stalagmite, every accessible part of which apparently belonged to the Old crystalline Floor, and rested on the Rock-like Breccia. The two, conjoined, not only filled the Chamber, but there was nothing to show that the Stalagmite did not extend upwards to the external surface of the hill. There was no trace of limestone visible; and the workmen had to hew their way through two kinds of material, each more intractable than any ordinary rock, and manfully they addressed themselves to their protracted toil, feeling some gratification in the fact that every inch they advanced was so much added to what had been previously supposed the entire extent of the Cavern.

With some reluctance, it was decided to abandon the practice of breaking up the entire mass of Stalagmite. The men were directed to remove the lower or basal portion of it only, to excavate the underlying Breccia to the depth of five feet instead of four, which from the beginning to this time had been the invariable practice, to leave the upper and greater part of the Stalagmite intact overhead, and to cut a tunnel beneath it, laying bare the limestone wall of the Cavern on each side.

The Stalagmite, as well as much of the Breccia, could only be removed with the aid of gunpowder; and considerable care and judgment were required in order that the remains of bear which both contained, and with which the latter was crowded, should be injured as little as possible.

The Committee have remarked in previous Reports that, on account of its comparatively loose texture, stalagmite is blasted with great difficulty. All, however, that the workmen had previously experienced in this way was inconsiderable in comparison with what they have encountered during the last twelve months. In addition to the usual difficulties, there were others arising from the existence of cavities in the mass, one of which had a capacity of upwards of a cubic yard, into which the boring tool would unexpectedly plunge to inform the men that their labour had been in vain. Not unfrequently a hole which had been bored with great labour, and appeared to be quite satisfactory, would prove to be incapable of being fired on account of its rapidly filling with water, which oozed through the Stalagmite as through a sponge.

The Crypt of Dates.—The Western Division of the Cavern, no part of which has yet been explored by the Committee, bifurcates towards its south-western extremity, and, so far as is at present known, terminates in two capacious chambers, termed the "Cave of Inscriptions" and the "Bears' Den." From the north-east corner of the latter, there extends a narrow gallery between almost vertical limestone walls. The greater part of it was, from time immemorial, occupied by a pool or "Lake" of water about 20 feet long, 8 feet broad, and of unknown depth. It was commonly regarded as the end of the Cavern, and was separated from the Bears' Den by a consi-

derable mound of Stalagmite. This Lake has called forth much speculation. Mr. Northmore believed the Cavern, of which he was the earliest explorer, to have been a temple of Mithras, and he spoke of the water as "the baptismal lake of '*pellucid water*'"^{*}. Others have occupied themselves with guesses respecting the source whence the Lake received its supply, and the mode by which it was kept from overflowing. Some held that it was fed by a small perennial spring; others that it was replenished by the drip from the roof only; whilst a third party contended that there was neither waste nor supply, and that the water ebbed and flowed synchronously with the tides of the ocean.

It is said that one adventurous visitor climbed along its northern or least precipitous side from one end to the other; but, according to the current belief, those who gained the further end usually did so by swimming. They all are said to have brought back the report that the Cavern extended "a very little way beyond the water" Mr. McEnery, speaking of the water, says, "the Cave beyond it deserves no particular notice; Admiral Sartorius and others have swam across"[†].

From the direction and length of the passages leading to them, it was obvious that the Bears' Den and Lake could not be far removed from the South-west Chamber. In this opinion the Superintendents were confirmed by the fact that when, from time to time, they visited the Den during the progress of the excavation of the Chamber, they heard the sound of the workmen's tools with great distinctness, and increasingly so as the work advanced, until at length their voices were heard, and ultimately conversation could be carried on, by means of shouting, however, rather than talking. Finally, on removing the *Modern granular Stalagmitic Floor* in the north-west corner of the Chamber, where it was in contact with the limestone roof, a hole, about 3 inches across, and extending obliquely upwards, was disclosed in the limestone, and it was observed that a current of air occasionally passed through it alternately in opposite directions. The workmen were directed to enlarge the hole by breaking away the limestone, and to ascertain whither it led. As soon as it was of sufficient dimensions, the younger workman, John Farr, ascended through it, and after a short time returned, stating that from the hole he entered a somewhat tortuous passage, having an easterly direction through the limestone, and so narrow and low that it could only be traversed by lying prostrate, and adopting a vermicular motion; that after a few feet he entered a longer passage in which it was possible to turn round and, in some places, to stand erect; that this second passage had a north and south direction, extending both ways a few feet only beyond the point at which he had entered it; that the inner or northern end was closed with stalagmite, on which he observed "writing," and that it terminated southward on the end of the Lake most remote from the Bears' Den.

Farr's report induced the other workman, George Smerdon, and one of the Superintendents, to follow his steps, when they found his description to be correct in all respects. It was further observed that the floor of the longer or north and south passage was entirely composed of stalagmite, and was, in fact, the upper surface of the mass beneath which they had begun to tunnel, and the greater part of which, on account of its enormous thickness and its intractability, they had reluctantly decided to leave intact. At the inner end this floor rose in the form of a steep irregular talus, on which, as well as on

^{*} See *Trans. Devon. Assoc.* vol. ii. p. 479-495 (1868).

[†] *Ibid.* vol. iii. p. 242 (1869).

the walls of the crypt, was the "writing" of which John Farr had spoken. This proved to be a series of initials and dates, amounting, probably, to upwards of a hundred, inscribed on the Stalagmite. Amongst the dates are those of 1744, 1728, 1702, and 1618. In several cases the scribes cut the figure of a square, and inscribed their initials within it.

Inscriptions in more accessible parts of the Cavern have long been well known. The most famous is the following in the "Cave of Inscriptions:"—"Robert Hedges of Ireland, Feb. 20, 1688," which there is good reason to believe is really as old as it professes to be, thus rendering it not improbable that those discovered in the crypt are genuine also.

In looking at those dates, it seems impossible to abstain from reflecting on the facts that they are cut on the upper surface of a mass of stalagmite upwards of 12 feet thick, in a locality where the drip is unusually copious; and that two and a half centuries have failed to precipitate an amount of calcareous matter sufficient to obliterate incisions which at first were probably not more than an eighth of an inch in depth.

It is scarcely necessary to observe that if the Stalagmite had been entirely broken up, as was at first intended, the inscriptions would have been destroyed with it; or that the discovery of them confirmed the decision to remove no more of the nether surface of the floor than would suffice to give the workmen sufficient height for their labour.

The Lake.—As the workmen advanced steadily towards the south-west, every step rendered it more and more probable that a passage would be laid open, leading out of the South-west Chamber in the precise direction of the Lake, and thus furnished an additional motive for tunnelling beneath the floor, in order that the Lake-basin might be preserved.

The removal of the Breccia, and of that part of the Stalagmite immediately above it, disclosed the fact, with which, indeed, the Superintendents were already familiar, that stalagmite is by no means impervious to water. Increased proximity to the Lake rendered this not only more and more patent, but augmented the difficulty of blasting the mass, and caused the labour to be one of great discomfort. It was therefore found necessary to tap the Lake to allow the water to escape. As soon as it was sufficiently dry, the workmen were directed to remove and examine carefully such deposits as might be found lying on the Stalagmitic Floor of the basin. They proved to be, first, or uppermost, the Modern Floor of Stalagmite; second, the ordinary Cave-earth, beneath which was the Old Crystalline Stalagmite of great thickness.

The Stalagmitic Floor, overlying the Cave-earth, was from 10 to 12 inches thick. It was finely laminated, and was soil-stained throughout; but, except at the ends of the basin and along its northern side, where portions of it remained *in situ* in a coherent but brittle condition, it was everywhere resolved into an almost impalpable paste, which, on being subjected to hydrochloric acid, rapidly effervesced and left very little residuum. A heap of this paste thrown outside the Cavern has, on exposure to the weather, hardened into a coherent mass.

In this pulpy mass were found numerous objects, none of which were of much interest, as the following list shows:—

1. Extemporized wooden candlesticks, such as are commonly used by those who visit the Cavern.
2. Pieces of candle.
3. Stems and bowls of clay tobacco-pipes, one of the former being unusually large.

4. Bottles of various kinds—wine, lemonade, and ginger-beer; some entire, but most of them broken.

5. Wine and other glasses, all broken.

6. Fragments of earthenware and china cups.

7. Numerous sticks and branches of trees; many of them charred.

8. A tin scone.

9. A small iron claw-hammer.

10. The handle of a hammer.

11. A clasp-knife, shut.

12. A two-foot rule, closed.

13. The plate of a child's iron spade.

14. A wooden ink-bottle (?).

15. An oyster-shell.

16. A pecten-shell, apparently used to hold some kind of paint.

17. A wooden spatula.

18. A wooden tally, having the initials W. R. cut on it.

19. A well-squared block of wood, above 5 inches long and broad, and $2\frac{3}{4}$ inches thick.

20. A wooden cover of a salting-pan, or of a small furnace.

21. A portion of a stout iron chain, 44 inches long, consisting of twenty-four links and a swivel, and having a padlock at one end.

22. Numerous broken stalactites, pap-like stalagmites, pebbles, and blocks of limestone.

Many of the objects (such as the candles, candlesticks, bottles, glasses, &c.) present no difficulty. They were, no doubt, thrown into the Lake in frolic, or by those who did not care to carry them further after they had ceased to be of service. Others (such as the knife, foot-rule, hammer, &c.) were probably dropped unintentionally; and the cover of a salting-pan or furnace, as well as the block of wood, may have been used to float candles by the curious. It does not seem easy, however, to account for the chain. It is not an object likely to have been useful during visits to the Cavern, nor is it such as people commonly carry about with them. The pebbles were thrown in, perhaps, in order to the formation of an opinion respecting the depth of the water; and the larger stones probably for the same purpose, or perhaps to be used as stepping-stones by those who desired to traverse the Lake.

It is perhaps worthy of remark that there are no mediæval or ancient objects; nor any such as might have been cast in as votive offerings by people who regarded the water with religious veneration.

Mr. McEnery seems to have believed that there were probably objects of interest in the Lake; he says, "We ought to rake it out" *.

In the underlying Cave-earth in the Lake there were found a fragment of an elephant's jaw containing a perfect molar, the finest specimen of the kind with which the labours of the Committee have been rewarded; a molar of a horse; several more or less perfect bones, including a humerus, an ulna, a scapula, and radii; and a fragment of a large horn-core.

That the Lake was supplied with water by infiltrations through the roof exclusively there is now no manner of doubt, and that some portion of it oozed away through the Stalagmite composing the bottom of the basin is no less certain. The mechanism, however, which rendered it impossible for the Lake to be filled to overflowing was, on examination, very patent and interesting. In its left wall, which is almost naked limestone, there is a natural tunnel

* See Trans. Devon. Assoc. vol. iii. p. 242 (1869).

or watercourse about 30 inches high and 20 inches wide, the base of which, at its junction with the Lake, is 8 inches below the highest level to which the water could rise, and forms an ascensive inclined plane, having an inclination of 3° , and a length of about $3\frac{1}{2}$ feet. Beyond this point the inclination is in the opposite direction, and is very much more rapid. Beyond a distance of 18 feet its course has not been traced, but it seems to ramify in various directions through the limestone. At the common vertex of the two planes, a diaphragm of stalagmite about 9 inches high and something more than 1 inch thick, extends quite across the tunnel from wall to wall, having its upper edge sensibly horizontal, and leaving above it a free open passage several inches high. It is obvious that whenever the water attained to this level the Lake was full, and that the surplus flowed over the diaphragm of stalagmite or natural weir. The fact that this regulated the maximum level of the water is confirmed by a corresponding and strongly marked high-water line along the entire boundary of the Lake. It is equally evident that unless there had been some other means of escape, this height, once reached, would have been permanent. During protracted droughts, however, the water has been known to fall upwards of 2 feet below this level—a fact accounted for by the slow oozing of the water through the Stalagmite.

The entire circumference of the Lake, and especially the almost vertical limestone wall on the south, is thickly studded with coralloidal tubercles of arragonite of various sizes, extending from the high-water to the low-water line. Indeed, they occur quite to the bottom of the Lake, but are less abundant than in the zone just mentioned.

Many parts of the Cavern present phenomena and problems of interest to the physicist as well as to the anthropologist and palæontologist. Thus, to go no further than the Lake, there are:—first, the facts that, at one period, the water entering through the limestone roof formed a floor by precipitating carbonate of lime, and that subsequently water, finding access through the same channel and lodging on this very floor, was capable of dissolving it and reducing it to a mere paste, apparently as calcareous as when it was in the coherent condition; second, that during the work of destruction, coralloidal masses of arragonite were formed on the naked limestone and Old stalagmitic walls, but chiefly on the former; third, that the water had slowly increased the capacity of the Lake, by building a weir of stalagmite entirely across the narrow tunnel which formed its principal outlet; and, fourth, that had time been allowed, this latter process must ultimately have closed the outlet and entirely changed the drainage of the Lake.

From the inscriptions in it, the number of persons who, from time to time, visited the Crypt of Dates, must have been very great; and every one of them must have taken the same route, namely, along the entire length of the Lake. The earliest known mention of the water is that by Polwhele in 1797, in his 'History of Devonshire',* when its condition appears to have been identical with that in which the Committee found it. Assuming it to have existed, and in the same state when the inscriptions were cut, the scribes must have performed the journey by wading through it, by using a float, by climbing along its almost precipitous northern wall, or by swimming. The last is perhaps the most probable mode; but in either case they must have provided themselves with the requisite tools and with an adequate supply of candles. In some cases the work appears to have consumed a considerable amount of time. If, however, it is supposed that at

* The 'History of Devonshire,' 3 vols. 1797, vol. i. pp. 50, 51.

least most of the inscriptions belong to the time when the upper Stalagmitic Floor of the Lake was yet undissolved, much of the difficulty will disappear, as wading would then have been easy—the Stalagmite would have afforded firm footing, and the depth of the water would not have been very considerable, even if permanently at the overflowing level, and the weir had been as high as it is at present.

The Water Gallery.—Having completed the excavation of the Lake, the workmen resumed their tunnelling operations in the recess or passage leading out of the South-west Chamber in a south-westerly direction, and which, as had been anticipated, was found to extend beneath the floor of the basin and along its entire length. To this branch it is proposed to give the name of “The Water Gallery;” and probably no part of the Cavern surpasses it in interest or importance.

As might have been expected, the deposit it contained was made up of the same materials as everywhere else were found beneath the Old Floor of crystalline Stalagmite—dark red earth; angular, subangular, and rounded pieces of grit not derivable from the Cavern hill, but which the neighbouring and loftier Lincombe and Warberry hills can supply; angular pieces of limestone, and pieces of stalagmite (some of them of great size), which, of course, were remnants of a floor more ancient still than the Old crystalline Floor which lay *above* the Breccia and below the Cave-earth. The points in which the Breccia differed from the Cave-earth were the darker colour of the red soil forming its staple and the much greater prevalence of fragments of grit. By the latter character alone it is very easy to distinguish the materials of the two deposits when thrown into the huge mass of refuse which the workmen have lodged outside the Cavern, especially after exposure to a shower of rain. Many of the pieces of grit, both angular and rounded, were of a very dark colour, and some of them had a polished metallic aspect, somewhat like that of a black-leaded hearthstone. The removal of the smallest splinter, however, showed that both colour and polish were superficial.

Along a considerable part of the length and breadth of the Water Gallery the Breccia, instead of being in contact with the nether surface of the Stalagmitic Floor which formed the bottom of the Lake, was separated from it by a vacuous interspace, sometimes 14 inches deep. It may be described as a rudely lenticular space, as it was of greatest depth in the middle, and, if the phrase is allowable, thinned off in every direction. A correct idea of the complete insulation of this vacuity may be conveyed by stating that if any animal, however small, could have become its occupant it would have been a permanent prisoner unless it could have excavated for itself a passage by which to escape.

Here and there, moreover, the vacuity was interrupted by what may be called “outliers” of Breccia, which reached, and were firmly adherent to the Stalagmite above. In every other part, the ceiling, or lower surface of the Stalagmite, retained traces of the deposit which had once been in contact with it, and on which, indeed, it had been formed. To it there clung angular and rounded pieces of rock, blocks of “*Older*” Stalagmite, and bones, teeth, and almost entire skulls of the Bear; whilst between them, in the ceiling, were the cavities once filled by similar objects, but which had fallen out and were found on the surface of the Breccia beneath. From the ceiling, too, there shot downwards numerous thin pipes of stalactite, of the thickness and colour of goose-quills, some of which reached the Breccia. The surface of the latter deposit beneath was here and there covered with

patches of modern stalagmite, occasionally incorporating pipes of stalactite, such as have been just mentioned, which by some means had been broken off. In fact a modern floor was in process of formation, vertically beneath the old one, by the agency of water filtering through the latter, and carrying with it the requisite calcareous matter.

As nothing would have been gained by their removal, the objects just described are left adhering to the ceiling—a fact which induces visitors to regard the Water Gallery as the most attractive branch of the Cavern.

All that portion of the Breccia which was not more than about a foot from its upper surface, and about a yard from the south wall of the Gallery, was invariably cemented into a firm rock-like concrete, but at all lower levels, and at greater distances from the south wall, it was perfectly incoherent. Where it was cemented it was crowded with fossils, but where it was not, there were none. The former was its almost uniform condition in the adjacent South-west Chamber and Lecture Hall, where its fossils formed a very large percentage of the entire mass.

The problem of the severance of the Breccia from the Stalagmite closely occupied the attention of the Superintendents whilst the excavation of the Water Gallery was in progress. There appear, *a priori*, to be three possible solutions,—first, that a stream of water had insinuated itself between the deposit and the floor, and had carried off the detritus which once filled the interspace; second, that, through failure of support at the base, the Breccia had sunk away from the Stalagmite to a slightly lower level; and, third, that water passing slowly through the floor had carried the finer particles of the detritus from the top of the Breccia to lower levels, lodging a portion of them in such interstices as it encountered, and perhaps carrying off the residue as colouring-matter.

The first is met by the fatal objection that there is no channel, large or small, either of ingress or egress, for the hypothetical stream, or the matter it is supposed to have removed.

Since the vacuity was both partial and discontinuous, the second suggested solution requires that the supposed failure at the base should have had the same characters, and hence that the Breccia should have been faulted. To this latter point the closest attention was given from first to last, and no trace of anything like a fault was ever detected.

The third hypothesis presupposes that both the Stalagmite and the Breccia are permeable by water. On neither of these points is there any doubt. Water has been seen oozing through this very Stalagmite, and it is well known that pools which in wet weather are formed on the Breccia disappear in a short time on the cessation of the drip. Indeed, when the Lake was tapped, the water was led to a depression in the surface of the Breccia in the South-west Chamber, and in less than a week the greater part of it had disappeared. There seems to be little doubt that the third is the true solution of the problem of the severance in the Water Gallery.

The animal remains found in that branch of the Cavern at present under notice were, so far as is known, exclusively those of Bear; and many of them are fine specimens, including some splendid canines and molars. Many of the bones were found broken, and some of them had been certainly fractured where they lay, as the parts remained in juxtaposition and, indeed, are reunited by some natural cement. When first exhumed, many of them were so soft that in cleaning them it was found that a soft brush left its traces on their surfaces. Exposure to the air hardens them. Some of the canines have obviously seen considerable service. Many of the molars are

beautifully white and fresh, and it is rarely possible to detect any evidence of wear on them. This latter fact was noticed by Mr. McEnery when speaking of the Bears' molars found in a similar deposit in the adjacent Bears' Den; and was supposed by him to "intimate that the Bears of those days were less exclusively frugivorous than the modern species, and lived partly on flesh" *.

In their Fourth Report, the Committee, speaking of the deposit under the Old crystalline Stalagmite, remarked, "Up to this time the Rock-like Breccia has been utterly silent on the question of the existence of Man; it has given up no tools or chips of flint or bone, no charred wood or bones, no bones split longitudinally, no stones suggesting that they had been used as hammers or crushers. But whilst they have before them the lessons so emphatically taught by their exploration of the Cavern, the Committee cannot but think that it would be premature to draw at present any inference from this negative fact" †.

The cautiousness inculcated in this passage received its justification on March 5, 1869, when a flint flake (No. 3991) was discovered in the Breccia in question in the Water Gallery. The particulars of this discovery were forwarded to Sir Charles Lyell, Chairman of the Committee, by the Superintendents, in the following passage in their Monthly Report, dated April 8, 1869:—"It was found with portions of the teeth of the Cave-bear, lying on a loose block of limestone, in contact with the north wall of the Gallery, in the third foot-level; that is, from 2 to 3 feet below the surface of the Breccia. A section at right angles to its longest axis would be a scalene triangle. The face of the flake represented by the smallest side is the natural surface of the flint nodule from which the specimen was struck. It required no more than three or, at most, four blows to produce it. On its larger face the bulb of percussion is well pronounced. It is partially coated with a thin ferruginous film, occasionally dendritic, and resembling that which commonly coats the pebbles found in the Breccia. Beneath this partial envelope it is of a light buff-colour. Its aspect is unlike that of any implements or flakes found in the Cave-earth. None of its edges can be said to be keen, yet it does not appear to have been rolled. One well-rolled small flint pebble occurred in the Breccia in the Gallery.

"Though the flake cannot be regarded as a *fine* specimen, we think there is little or no doubt that it was formed by human agency, and assuming this to be the case, it appears to us to be of very great value, as it was found in a deposit not only older than the ordinary implement-bearing Cave-earth, but separated from it by the Old Floor, which in some cases was upwards of 12 feet thick, and which is certainly of great thickness immediately above the spot where the flake lay. In fact, it was found in a deposit which, so far as the Cave evidence goes, was laid down before the introduction of that in which were entombed the first traces of the Cave-hyæna, Cave-lion, Mammoth, and their contemporaries.

"Being impressed with the probably great importance of the discovery, we carefully addressed ourselves to the question, 'Did the flake originally belong to the comparatively modern Cave-earth in the Lake above and find its way through some crevice in the Old Floor which forms the ceiling of the Gallery?' To this important question we are prepared to give a negative reply; for—

"1st. No crevice or hole of any kind is discoverable in either the upper or lower surface of the ceiling or *Old Floor*.

* See Trans. Devon. Assoc. vol. iii. p. 366 (1869).

† Brit. Assoc. Report, 1868, p. 54.

"2nd. The flake was not found vertically beneath any part of the Lake, but fully a yard beyond its nearest margin.

"3rd. It did not lie on the surface of the deposit, but from 2 to 3 feet beneath it.

"4th. If the flake was originally lodged in the Cave-earth found in the Lake, it must have been the only one deposited there; for when we carefully and completely emptied the Lake no flint implement was met with.

"5th. If the flake had found its way through the Stalagmite, it might have been expected that some such bones as were found in the Lake (Horse and Mammoth, for example) would have descended through the same crevice; but instead of this, the remains of the Cave-bear alone are met with in the Breccia, and teeth of this animal were found in contact with the flake itself.

"In short, there is no crevice through which the object could have passed; if it descended through the floor, it descended alone; and if it did so descend, it ought not to have been where it was found. We have no hesitation in stating that the flake is of the same age as the Breccia which contained it; and that if our opinion of its human origin is confirmed, it is anthropologically by far the most important object the Cavern has yielded."

On June 3rd, 1869, the flake was submitted to Mr. John Evans, F.R.S., a Member of the Committee. He drew up the following statement, with the intention that it should be inserted in the present Report:—"No. 3991 is undoubtedly of human workmanship. It is a flake of flint from the Chalk, one of the smaller facets of which shows the natural crust of the nodule from which it was struck. The other external facet shows the characteristic depression arising from the bulb of percussion on the flake previously removed to form this facet. The flat or internal face of the flake shows a well-developed bulb, and the large but-end where the blow was struck has been fashioned by two or three blows. It has therefore taken four or five blows, each administered with a purpose in view, to produce this instrument.

"Not only, however, has it been artificially made, but it carries upon it evidence of having been in use as a tool; for the edge produced by the intersection of the two principal artificial faces is worn away along its entire length, and exhibits the slightly jagged appearance produced by the breaking off of the sharp edge, such as I find by experience to result from scraping bone or other hard substances with the edge of a flint flake.

"(Signed) John Evans, June 3, 1869."

Besides the above, a small perfectly angular piece of coarse-grained white flint (No. 4037a) was discovered in the first foot-level of the Breccia in the Water Gallery on Friday, April 23, 1869. It has all the aspect of having been struck off in making an implement.

Having ascertained by careful measurements that a very few feet would take the workmen into the Bears' Den, it was decided to excavate the Water Gallery no further, as it was deemed undesirable to commence the investigation of the Western Division of the Cavern so long as any branch of the Eastern Division remained unexplored.

The South Sally-Port.—Two long, comparatively narrow, and approximately parallel galleries extend in a south-easterly direction into the eastern wall of the Eastern Division of the Cavern, one from the Great Chamber, the other from the Lecture Hall. They were termed "The Sally-Ports" by Mr. McEnery, who believed that they ultimately led to external openings in the eastern side of the Cavern hill. On the discontinuation of the excavation of the Water Gallery, the exploration of the South Sally-Port, opening out of

the Lecture Hall, was commenced, and at present has been completed to upwards of 40 feet from the entrance.

For the first 15 feet there was the ordinary granular Stalagmitic Floor overlying the typical Cave-earth, but beyond that point there was no stalagmite, except a thin and very limited patch in one or two places. At the junction with the Lecture Hall the floor was 21 inches thick, but it became rapidly thinner as it extended inward; and for some feet it did not exceed an inch in thickness.

No part of the Cavern is at present less than this exposed to drip. It may not be out of place to state here, as a fact of, at least, large generality, and to which there is no known exception, that in those branches of the Cavern where the drip is at present very copious the Stalagmitic Floor is of great thickness; and where the drip is but little, there is either no floor or an extremely thin one; that, in short, the present amount of drip in any locality affords a good index of the thickness of the floor there, so that the external drainage of the Cavern hill appears to have undergone no change for a very lengthened period.

The South Sally-Port presented phenomena having no parallel in the experience of the Committee during the present exploration, but for which Mr. McEnery's "Cavern Researches" had prepared them. Speaking of the Sally-Ports, or "Long Tongues," he says, "their entire area is honeycombed with fox-holes, and the loam thrown up in mounds round their edges is mixed with scales of the beetle, modern and fossil bones, all of which, as well as the rocky contents, resembled bleached or calcined substances exposed on a common." Indeed his description of the South Sally Port is not very encouraging. He says, "In attempting to reach the extremity of the lower tongue at a point where it suddenly expands into a large grotto, the hollow floor gave way like a pitfall with my weight and sank into a cleft of the rock. I shall not dissemble my terror at my sudden descent. My efforts to escape would but cause the ground to sink still deeper and deeper into deeper abysses."

"At subito se aperire solum vastosque recessus
Pandere sub pedibus nigraque voragine fauces."

"The crash routed some animals from their subterranean abodes. I heard them forcing their escape towards the outside through the incumbent earth, and perceived their footmarks. The hounds frequently assemble outside about this point, and frequently earth foxes there" *.

Happily none of the present exploring party have experienced any inconvenience during their researches; but they are constantly meeting with tunnels in the Cave-earth, probably made by some burrowing animals, with ancient and modern bones commingled both on the surface and at all depths below it, with great clusters of the wing-cases of beetles exclusively on or very near the surface; and they have had impressed on them daily the important but familiar truth that unless sealed up with a Stalagmitic Floor, Cavern deposits are just as likely to be fraught with anachronisms as with a trustworthy chronological sequence.

During the present month (August 1869) one of the Superintendents has had occasion to pass frequently through "The Labyrinth," a branch of the Western Division of the Cavern. As he entered it on the 6th he observed some fresh Cave-earth lying on the floor where there was no stalagmite, and he directed the attention of the workmen to it. They had all passed along

* See Trans. Devon. Assoc. vol. iii. p. 302 (1869).

the same route the day before, and they were all satisfied that the earth was not there then. On examination it was found to have been thrown out of a newly made hole, in all respects resembling those made by rats, and extending from the edge of a slab of limestone obliquely through the Cave-earth beneath*.

In the South Sally-Port, the Black Mould, which in most of the other branches of the Cavern was found continuously overlying the Stalagmitic Floor, did not extend many feet within the entrance. Beyond the point at which the Stalagmite ended, the entire deposit was Cave-earth from top to bottom of the section, and in all probability every part of it had been introduced before the formation of the calcareous floor began. In previous Reports the Committee have recorded the fact that in the Stalagmite itself are lodged remains of the Cave-bear, Hyæna, and Rhinoceros. Indeed the only fossil found in the scanty floor in that branch of the Cavern now under consideration was a tooth of the last-named species, which is not only in quite the upper part of the stalagmitic sheet, but, instead of being completely covered, projected above its surface. Obviously, then, *Ursus spelæus*, *Hyæna spelæa*, and *Rhinoceros tichorhinus* outlived the era of the Cave-earth, and therefore it would not be surprising if their remains, together with palæolithic flint implements, were found lying on the surface of this deposit; nor, if they were left unprotected, would there be anything inexplicable or strange if they were found mixed with objects belonging to more recent periods, or even to the present day. Such a commingling might or might not be the result of disturbance and rearrangement when occurring on the surface, but could not be otherwise explained when met with below it.

Be this as it may, it is undeniably the fact that in this, but in no other branch of the Cavern which the Committee have explored, ancient and modern bones, and unpolished flint implements and rude pottery, have been found lying together. Remains of the extinct brute inhabitants of Devonshire are mixed confusedly with those of the present day, and the handiwork of the human contemporary of the Mammoth is found inosculating with the product of the potter's wheel.

It is worthy of remark that whilst potsherds lie on the surface, and the mouths of shafts, connected with the tunnels or burrows, stand open to receive them, instances of their having fallen in are extremely rare. The modern objects found in the body of the Cave-earth are almost without exception such as have been actually taken in by the recent animals which made their homes there.

In a sensibly horizontal tunnel about the size of a fox-earth, at a depth of 4 feet below the surface, there was found a bell, such as huntsmen are wont to suspend to the neck of a terrier when sent in after a fox—a fact which in all probability explains its presence in the spot it occupied.

In other and smaller burrows bundles of moss, each about the size of a man's fist, have been met with and supposed to be the nest of some animal.

Compared with the phenomena of every other branch of the Cavern explored by the Committee, those of this Sally-Port are no doubt anomalous;

* The visits of rats to the Cavern and their habit of carrying off candles have long been well known. In January 1867 the workmen observed a rat in the Cavern on several successive days. At length he made his presence felt in a very disagreeable manner. At 9 a.m. the principal workman placed his dinner, carefully lodged in a bag, in a stout wicker basket. At the dinner-hour (1 p.m.) he found that the rat had eaten a hole through the basket, another through the bag, and carried off every particle of his meal. Poisoned food was at once prepared for the intruder, and nothing further was seen of him until a few days after his dead body was found.

but regard being had to the condition of the deposit in which they occur, they are certainly such as might have been looked for, and they present no difficulty whatever.

Notwithstanding the obvious disturbance of the Cave-earth, the same method of exploration has been followed here as elsewhere; and the specimens found in each "level" and "yard" have been kept apart in separate boxes as heretofore.

Scarcely any branch of the Cavern has surpassed this Sally-Port in the number of the fossils it has yielded, and in no part have finer or more perfect specimens been found. They are the remains of all the common Cave-mammals, with a greater number of the teeth of the Mammoth than have been met with by the Committee within an equal space elsewhere. The bones are generally of less specific gravity, softer, and more brittle than those found in the Cave-earth in other branches of the Cavern—a fact perhaps ascribable to the absence of a calcareous drip. Many of them are gnawed, some have entirely escaped this ordeal, and a few have marks on their surfaces apparently unlike those produced by teeth. Most of them on being cleaned retain impressions of the brush used for that purpose. The surfaces of several are more or less covered with rudely circular punctures of various sizes—a fact observed occasionally in those found elsewhere, but much less frequently than in these in this branch of the Cavern. Lumps of faecal matter are by no means rare.

The flint and chert implements and flakes are ten in number, three of which were met with on the surface, one in the first foot-level, three in the second, two in the third, and one the position of which is somewhat uncertain.

Four of them only need description. The first (No. 4155) is a splendid heart-shaped chert implement. It was found June 12, 1869, lying on the surface of the Cave-earth, beneath an overhanging ledge of limestone which it almost touched, on the west side of the Sally-Port. It was wrought from a chert nodule apparently selected from the supracretaceous gravel of Milber Down between Torquay and Newton Abbot. It is about $4\frac{1}{4}$ inches long, 3 inches in greatest breadth, and $1\frac{3}{4}$ inch thick at $1\frac{1}{4}$ inch from its broad end. The but-end only retains the original surface of the nodule. It is the only implement of the kind found by the Committee, and none of those figured by Mr. McEnery at all resemble it.

The second (No. 4259) is of fine-grained silvery grey flint. It is symmetrically canoe-shaped, 3·6 inches long, 1·2 inch broad, and ·4 inch in greatest thickness. It is flat on one side, somewhat rounded on the other, worked to an edge all round the margin, and considerably chipped on both surfaces. It belongs to the same type as the implement (No. 3922) previously described, but is much less rounded on the outer surface. It was found on the Cave-earth, July 5, 1869.

The third (No. 4263) is formed of rather coarse white cherty flint. It is flat on the inner surface, carinated on the outer, and is not highly finished. It is about 4 inches long, 1·3 inch broad, ·6 inch in greatest thickness, and was found July 6, 1869, 2 feet deep in the deposit.

The fourth is strongly carinated on the outer surface; the inner is very concave longitudinally, and slightly convex transversely. It is 3·4 inches long, 1·2 inch broad, and ·5 inch where thickest. It is chiefly remarkable from having a square tang at one end, ·8 inch long and ·6 inch broad, as if for fastening into a haft. Its opposite end is rounded, it is fined off to an edge all round, and it appears to have been used as a scraper. It was found August 5, 1869, 40 feet from the entrance of the Sally-Port, in a small mass

of Cave-earth which, without being observed, had slipped off the face of the section; hence its exact position is uncertain.

Charcoal has been found somewhat plentifully on the surface, where a few burnt bones occurred with it. It has also been met with at all depths in the deposit, though in no great quantity.

A few marine shells of common species were met with on the surface.

The fragments of pottery differ in colour and in finish, and probably belong to more than one period. Two or three of them are rather longer than those commonly found in the Cavern.

During the last twelve months Mr. Boyd Dawkins, assisted by Mr. Ayshford Sanford, has made considerable progress in identifying and naming the fossils. He has prepared and sent in a Catalogue of a large number of specimens, accompanied by the following Report.

In the determination of the following animals from Kent's Hole Cavern I have been aided by my friend Mr. Ayshford Sanford. By far the greater portion of the labour has been undergone by him. We have examined upwards of four thousand specimens, or rather less than one-tenth of the whole accumulation of the remains in the hands of the Committee. No bones of birds or fish have been catalogued; the latter Dr. Günther has kindly undertaken to name before our Report is concluded. The results of our work are contained in the following catalogue.

Homo.—We have met with no bones or teeth from the Cave-earth that can be ascribed undoubtedly to man. One or two much-worn or mutilated incisors, however, may be human, but they may also belong to several other animals. The human remains from the prehistoric deposit of Black Mould are exceedingly abundant, and many of them, in Mr. Sanford's opinion, bear evidence of the former existence of cannibals in the Cave. Some of them have been cut and scraped by sharp instruments, the marrow-bones are broken, and are mixed indiscriminately with the broken bones of Sheep or Goat, Red Deer, *Bos longifrons*, and other animals. In one box there are the remains of at least three individuals—a large man, a nearly full-grown woman or lad, and a child about half-grown.

Man has also left his handiwork on some very remarkable fragments of canines of Bear from the Cave-earth, which, in common with many other splinters of bone, are in a totally different mineral condition to that presented by the ordinary Cave-remains. They are much more crystalline, much heavier, and of a darker colour than the ordinary teeth and bones, and have been so mineralized that they present a fracture almost conchoidal, and strongly resembling that of a Greensand chert. One of these had been fashioned into a flake, and one of its surfaces presented the usual traces of use. It had manifestly been formed after it had lost its normal dentinal texture. It is clear, therefore, that they had become fossilized before the introduction of the present Cave-earth. Viewed in connexion with the evidence of the existence of an ancient floor that is now represented by masses of stalagmite, sometimes ossiferous, we cannot resist the idea that they are samples of the contents of the Cave which had in the main disappeared before the introduction of the present Cave-earth.

Felis spelæa.—The Cave-lion is tolerably abundant in the Cave-earth.

Felis, sp.?—A single canine from the Cave-earth indicates an animal of the size of *Lynx cervaria*.

Felis catus?—A lumbar vertebra from the Cave-earth corresponds in size with that of the Wild Cat.

Hyæna spelæa.—The Cave-hyæna is very abundant in the Cave-earth.

Canis lupus.—The Wolf, on the other hand, is comparatively rare.

Canis domesticus.—The remains of the Dog are sparingly met with in the Black Mould, and indicate the presence of more than one variety.

Canis vulpes.—The Common Fox is found in the Black Mould, and sparingly in the older subjacent deposit.

Canis vulpes (var. *spelæus*).—Vulpine bones, on the other hand, from the Stalagmite and Cave-earth indicate an animal larger and stouter than the English Fox. These are not found in the Black Mould.

Canis (size of *C. isatis*).—With the larger bones there are a few much smaller than those of the Common Fox, that correspond most closely with those of *C. isatis*. The vulpine skulls, however, in the Taunton Museum, from the Mendip Caves, rather indicate a species closely related to *C. isatis* than a specific identity, since the true molars are somewhat broader. It is well to mention that Mr. Sanford has identified a portion of a skull found along with the remains of *Hyæna*, in a cave on the opposite side of Torbay, as belonging to *Canis isatis*.

Gulo luscus.—A single os innominatum of a nearly full-grown Glutton indicates the presence of this rare mammal in the Cave-earth. Although it belonged to an animal not quite adult, it agrees almost exactly in size with that of a fully grown male from Sweden.

Meles taxus.—The remains of the Badger are abundant in the prehistoric Black Mould, rare in the Cave-earth. In the latter case we doubt the truly fossil condition of the bones.

Ursus spelæus.—The bones and teeth of the Cave-bear from the Cave-earth indicate greater variation of size than those of any other wild animal with which we are acquainted.

Ursus priscus = *ferox*.—This species, which has been proved by Mr. Busk to be undistinguishable from those of the North-American Grizzly Bear, occurs abundantly in the Cave-earth, as it does also in the caves of the Mendip Hills. The short stout bones of *U. spelæus* are represented by flatter, longer bones of *U. ferox*, that are for the most part distinct from the rounder bones of *U. arctos*. We therefore have attributed the isolated flat long bones to the second of these species. Bones of intermediate form, however, occur which appear to connect the two forms. They are more constant in size than those of the other two bears.

Ursus arctos.—Teeth and bones of the Brown Bear, still living in Europe, occur, but not very commonly, in the Cave-earth. Some of those from the Black Mould are evidently derived from the lower and older beds; but others, from their condition, apparently belong to animals that lived at the same time as *Bos longifrons* and the Sheep or Goat of the Black Mould.

Elephas primigenius.—The Mammoth is but sparingly met with in the Cave-earth.

Rhinoceros tichorhinus.—The remains of the Woolly Rhinoceros are abundant in the Cave-earth.

Equus caballus.—The Horse is the most abundant fossil in the Cave-earth. Many of the teeth are more or less plicident, but we are unable to draw any sharp line separating the *Equus plicidentis* of Prof. Owen from the recent species. They present almost endless variations in this respect, and were apparently in a state of transition from the plicident to the common type in the postglacial times.

Bos primigenius.—The Urus exists somewhat sparingly in the Cave-earth.

Bison priscus.—The Bison, on the contrary, is much more common in the same deposit.

Bos longifrons.—Bones and teeth of the Celtic Shorthorn occur in the Black Mould. The small bones in the Cave-earth belong to the preceding species.

Cervus megaceros.—The Irish Elk is not uncommon in the Cave-earth.

Cervus elaphus (= *Strongyloceros spelæus*, Owen = *C. destremii*, Serres).—We have come to the conclusion that the Red Deer was more variable in size during the postglacial period than at the present day. Some teeth are not larger than those of a small hind from the Hebrides, while others surpass in size those of the largest Haddon or Horner Hart. Some even almost rival those of the smaller specimens of the Irish Elk. The animal occurs both in the superficial Black Mould and in the Cave-earth.

Cervus tarandus.—The Reindeer is abundant in the Cave-earth.

Cervus capreolus.—We have met with the Roedeer only in the Black Mould; it was evidently a common article of food.

Ovis aries, *Capra hircus*.—The Sheep and the Goat are abundant in the Black Mould.

Sus scrofa.—The Pig occurs in the Black Mould only; it is small in size, and was evidently an article of food.

Lepus timidus.—The remains of the common Hare are abundant in the Black Mould, but are rare in the Cave-earth and Stalagmite. In these deposits they are for the most part replaced by larger and stouter bones, which may perhaps be referred to *Lepus diluvianus* of the French naturalists. These stout bones are very rare in the Black Mould.

Lepus cuniculus.—Bones of the Rabbit are abundant in the Black Mould; a single bone has occurred apparently from the Modern Stalagmite, but none from the Cave-earth.

Lagomys spelæus.—We have met in the Cave-earth with a lower jaw of the Cave Pika. It is rather smaller than the type, and is closely related to that of *Lagomys pusillus*.

Arvicola amphibius.—The Water-rat, or one of the closely allied varieties, we have met with, but not abundantly, in the Cave-earth and Black Mould.

Arvicola agrestis.—There are one or two specimens from the Cave-earth of this species that show the same variation in the direction of *A. ratticeps* which Mr. Sanford has remarked in jaws from the Mendip Caves.

Arvicola glareola (= *A. pratensis*).—We have met with a single lower jaw from the Cave-earth.

Arvicola Gulielmi.—This new species of Vole, discovered lately by Mr. Sanford in the caves of Mendip, is represented by a jaw from the Cave-earth. It may be recognized by its uniting a size which nearly approaches that of *A. amphibius* to the dentition of *A. subterraneus*.

Castor fiber.—We have met with five specimens of the Beaver from the Cave-earth.

Phocæna communis.—A solitary scapula of this cetacean has been furnished by the Black Mould.

In this list we have merely noticed the species that have passed through our hands, without reference to the previously published list of animals from the Cave.

Report of the Committee on the Connexion between Chemical Constitution and Physiological Action. The Committee consists of Dr. A. CRUM BROWN, Dr. T. R. FRASER, and Dr. J. H. BALFOUR, F.R.S. The investigations were conducted and the Report prepared by Drs. A. CRUM BROWN and T. R. FRASER.

Drs. BROWN and FRASER communicated to the Section, at the Norwich Meeting, the results of some experiments (the details of which have since been published in the Transactions of the Royal Society of Edinburgh) on the connexion between change of chemical constitution and change of physiological activity.

They have since that time continued their investigations by applying the method described in the above communication to the alkaloids, atropia, conia, and trimethylamine. The substances which they have compared in reference to their physiological action are, atropia and the salts of methylatropium, conia, methylconia, and the salts of dimethylconium, salts of ammonia, trimethylamine, and tetramethylammonium. They have made in all about 120 experiments, and give in the accompanying Table the results of thirty-six, in which the dose was not much above or below the minimum fatal. It will be seen that these results confirm the conclusions at which they formerly arrived, viz. that the action of compounds of triatomic nitrogen is different from that of compounds in which the nitrogen is stably pentatomic, and that salts of ammonium bases act on the peripheral terminations of the motor nerves in the same way as curara. This action, and the absence of convulsant action, appear to be generic characters of the salts of ammonium bases. Besides this, the salts of the ammonium bases frequently retain certain of the special (specific) actions of the nitrile bases from which they are derived.

Tabular Summary of Experiments with Doses that are about the minimum fatal.

Number of experiment.	Substance employed.	Animal and its weight.	Method of exhibition.	Dose.	Effect.
1.	Iodide of methyl-atropium.	Rabbit, 3 lb. 13½ oz.	Subcutaneously.	2 5 grs.	Dilatation of pupils; slight and then decided paralysis; faint tremors; and <i>recovery</i> (in more than two hours and ten minutes).
2.	Do.	Rabbit, 3 lb. 10 oz.	Do.	3 grs.	Ditto; and <i>death</i> (in fifty-eight minutes).
3.	Do.	Dog, 8 lb. 6 oz.	Do.	10 grs.	Dilatation of pupils; rapid and decided paralysis; very faint tremors; and <i>death</i> (in thirty-two minutes).
4.	Do.	Frog, 392 gr.	Do.	0·005 gr.	Paralysis; complete suspension of reflex excitability (motor-nerve conductivity being retained); and complete <i>recovery</i> (in less than two hours).

TABLE (continued).

Number of experiment.	Substance employed.	Animal and its weight.	Method of exhibition.	Dose.	Effect.
5.	Iodide of methyl-atropium.	Frog, 455 gr.	Subcutaneously.	0.025 gr.	Complete paralysis, with suspension of motor-nerve conductivity; and <i>recovery</i> (in less than twenty-four hours).
^a 6.	Do.	Frog, 422 gr.	Do.	0.1 gr.	Complete paralysis, with suspension of motor-nerve conductivity, during first, second, third, and fourth days; and <i>recovery</i> on fifth day.
7.	Do.	Frog, 260 gr.	Do.	0.3 gr.	Complete paralysis, with suspension of motor-nerve conductivity in thirty minutes; muscular contractility was retained until the sixth day; loss of muscular contractility and some <i>rigor</i> (<i>death</i>) on seventh day.
8.	Do.	Rabbit, 3 lb. 12 oz.	by stomach.	30 grs.	None.
9.	Sulphate of methyl-atropium.	Rabbit, 3 lb. 7½ oz.	subcutaneously.	2 grs.	Dilatation of pupils; decided paralysis; faint twitches; and <i>recovery</i> (in about thirty minutes).
10.	Do.	Rabbit, 2 lb. 7 oz.	Do.	2 grs.	Ditto; and <i>death</i> (in forty minutes).
11.	Do.	Frog, 460 gr.	Do.	0.1 gr.	Complete paralysis, with suspension of motor-nerve conductivity in about forty minutes; retained muscular contractility until fifth day; loss of muscular contractility with some <i>rigor</i> (<i>death</i>) on sixth day.
12.	Iodide of ethyl-atropium.	Rabbit, 3 lb. 8½ oz.	Do.	2 grs.	Dilatation of pupils; decided paralysis; faint tremors; and <i>death</i> (in about thirty minutes).
^b 13.	Sulphate of atropia.	Rabbit, 4 lb. 10 oz.	Do.	5 grs.	Dilatation of pupils, and no serious symptom.
14.	Do.	Do.	Do.	10 grs.	Ditto.
^b 15.	Do.	2 lbs. 5 oz.	Do.	15 grs.	Ditto, diuresis, catharsis, and languor, followed by <i>recovery</i> .

^a No symptom of exaggerated reflex activity occurred during this experiment.

^b Same rabbit at intervals of several days.

TABLE (continued).

Number of experiment.	Substance employed.	Animal and its weight.	Method of exhibition.	Dose.	Effect.
^c 16.	Sulphate of atropia.	Dog, 8 lb. 6 oz.	subcutaneously.	10 grs.	Dilatation of pupils; decided paralysis; frequent tetanus; and <i>recovery</i> .
17.	Sulphate of atropia.	Frog, 447 gr.	Do.	0.4 gr.	Incomplete paralysis first day; spasms second day; tetanus fourth to sixth days; stiff reflex movements seventh day; and <i>recovery</i> eighth day.
18.	Do.	Frog, 404 gr.	Do.	0.4 gr.	Complete paralysis first and second days; tetanus third to ninth day; spasmodic movements tenth and eleventh days; and <i>recovery</i> twelfth day.
19.	Hydrochlorate of methylconia.	Rabbit, 3 lb. 14½ oz.	Do.	0.1 gr.	No obvious effect.
20.	Do.	Rabbit, 2 lb. 10½ oz.	Do.	0.2 gr.	Exaggeration of reflex activity; decided paralysis; and <i>death</i> (in twenty-two minutes).
^e 21.	Do.	Frog, 175 gr.	Do.	0.2 gr.	Proof of paralysis of motor endorgans at early stage.
22.	Iodide of dimethylconium.	Rabbit, 3 lb. 6½ oz.	Do.	2.5 grs.	Slight paralytic symptoms and <i>recovery</i> .
23.	Do.	Rabbit, 4 lb.	Do.	3 grs.	Decided paralysis; faint tremors; and <i>death</i> (in about one hour and fifteen minutes).
^e 24.	Do.	Frog, 225 gr.	Do.	0.1 gr.	Complete paralysis for three days; and <i>recovery</i> .
^f 25.	Hydrochlorate of conia.	Rabbit, 3 lb. 6½ oz.	Do.	0.2 gr.	Tremors and decided paralysis; exaggerated activity; and <i>death</i> (in about thirty-two minutes).
^g 26.	Do.	Frog, 364 gr.	Do.	0.1 gr.	Paralysis of motor nerves, and <i>death</i> on fourth day.
^h 27.	Hydrochlorate of trimethylamine.	Rabbit, 3 lb. 2½ oz.	Do.	7 grs.	Very slight paralysis &c.; and <i>recovery</i> .

^c Same dog as used in experiment 3.^d Some evidence of reflex exaggeration.^e No evidence of exaggerated reflex activity.^f Dr. Christison's preparation; a specimen from Mr. Morson was found to be less active.^g Some evidence of exaggerated reflex activity.^h Strong odour in breath of trimethylamine in a few minutes.

TABLE (continued).

Number of experiment.	Substance employed.	Animal and its weight.	Method of exhibition.	Dose.	Effect.
28.	Hydrochlorate of trimethylamine.	Rabbit, 3 lb. 7½ oz.	Subcutaneously.	11 grs.	Slight sleepiness, salivation for a few minutes, defecation and urination, decided paralysis, spasms, and <i>death</i> .
29.	Do.	Frog, 345 gr.	Do.	0.5 gr.	Tonic spasm in anterior and left posterior extremities (right cut off from poisoning by ligature of its vessels); complete paralysis of left sciatic nerve (right remaining active); and <i>death</i> .
30.	Iodide of tetramethylammonium.	Rabbit, 3 lb. 1½ oz.	Do.	0.7 gr.	Salivation (very profuse and long continued); lachrymation; decided paralysis; slight tremors; and <i>recovery</i> .
31.	Do.	Rabbit, 2 lb. 14 oz.	Do.	12 grs.	Ditto; and convulsions; and <i>death</i> .
	Do.	Frog, 497 gr.	Do.	0.04 gr.	Tonic spasm, and motor endorgan paralysis; and <i>recovery</i> .
33.	Do.	Frog, 425 gr.	Do.	0.05 gr.	Ditto; and <i>death</i> .
34.	Chloride of ammonium.	Rabbit, 3 lb. 12 oz.	Do.	12 grs.	Partial paralysis; frequent tetanus; and <i>recovery</i> .
35.	Do.	Rabbit, 2 lb. 8 oz.	Do.	15 grs.	Decided paralysis; frequent tetanus; and <i>death</i> .
36.	Do.	Frog, 435 gr.	Do.	0.5 gr.	Partial paralysis; starts and other symptoms of reflex exaggeration; complete paralysis of motor nerves and muscles; and <i>death</i> .

¹ Evidence of motor nerves being paralyzed before muscles.

Of the various substances included in this Table, atropia possesses the most remarkable special (specific) actions, viz. a dilating action on the pupils and a paralyzing action on the cardiac inhibitory branches of the vagi nerves. It will be seen from the two following experiments that the salts of the methyl derivative of atropia retain these special actions:—

Experiment 37. One minim of a solution of 1 grain of sulphate of methyl-atropium in 100,000 minims of distilled water ($=\frac{1}{100,000}$ of a grain of sulphate of methyl-atropium) was placed on the right eyeball of a rabbit.

Before the application the right pupil measured $\frac{1}{8} \times \frac{1}{8}$, and the left $\frac{1}{8} \times \frac{1}{8}$ of an inch.

39 mns. after the application	"	"	"	$\frac{1}{8} \times \frac{1}{8}$	"	$\frac{1}{8} \times \frac{1}{8}$	"
1 hour	"	"	"	$\frac{1}{8} \times \frac{1}{8}$	"	$\frac{1}{8} \times \frac{1}{8}$	"
1 hr. 30 ms.	"	"	"	$\frac{1}{8} \times \frac{1}{8}$	"	$\frac{1}{8} \times \frac{1}{8}$	"
2 hs. 10 ms.	"	"	"	$\frac{1}{8} \times \frac{1}{8}$	"	$\frac{1}{8} \times \frac{1}{8}$	"
22 hrs.	"	"	"	$\frac{1}{8} \times \frac{1}{8}$	"	$\frac{1}{8} \times \frac{1}{8}$	"

Experiment 38. The two vagi nerves were exposed in the neck of a rabbit, and on separately subjecting the trunk of each nerve to galvanic stimulation of a certain strength (obtained by the use of Du Bois-Reymond's induction-apparatus), it was found that stoppage of the heart's contractions resulted on each occasion during the five seconds the galvanic stimulation was applied. A solution containing half a grain of sulphate of methyl-atropium in fifteen minims of distilled water was then injected under the skin of the abdomen.

5 minutes...	after the injection	the heart was contracting	28 times in 10 seconds.
7	"	"	28
7 mns. 10 secs.	"	the right vagus was galvanized for 10 seconds,	"
	"	and the heart continued to contract during the	"
		galvanism.....	28 times in 10 seconds.
10 minutes...	after the injection	the heart was contracting	29 " "
19	"	"	30 " "
20	"	the left vagus was galvanized for 10 seconds,	"
	"	and the heart continued to contract during the	"
		galvanism.....	30 times in 10 seconds.
20 mns. 20 secs.	after the injection	the heart was contracting	30 " "
26	" 0	"	30 " "
26	" 20	the right vagus was galvanized for 10 seconds,	"
	"	and the heart continued to contract during the	"
		galvanism.....	30 times in 10 seconds.

It was also found that the special actions on the pupils and on the cardiac inhibitory branches of the vagi nerves are possessed by the ethyl derivative of atropia.

Report of a Committee, consisting of Lieut.-Col. STRANGE, F.R.S., Professor Sir W. THOMSON, F.R.S., Professor TYNDALL, F.R.S., Professor FRANKLAND, F.R.S., Dr. STENHOUSE, F.R.S., Dr. MANN, F.R.A.S., W. HUGGINS, F.R.S., JAMES GLAISHER, F.R.S., Professor WILLIAMSON, F.R.S., Professor STOKES, F.R.S., Professor FLEMING JENKIN, F.R.S., Professor HIRST, F.R.S., Professor HUXLEY, F.R.S., and Dr. BALFOUR STEWART, F.R.S., appointed for the purpose of inquiring into, and of reporting to the British Association the opinion at which they may arrive concerning the following questions:—*

- I. *Does there exist in the United Kingdom of Great Britain and Ireland sufficient provision for the vigorous prosecution of Physical Research?*
- II. *If not, what further provision is needed? and what measures should be taken to secure it?*

Your Committee, having sought the counsel of many of the most eminent men of science of the United Kingdom upon these questions, so far as it was found practicable to do so, and having carefully deliberated thereon, have arrived at the following conclusions:—

- I. That the provision now existing in the United Kingdom of Great Britain

* The following names have since been added to the Committee:—Alfred Tennyson, F.R.S.; Lyon Playfair, F.R.S., M.P.; J. Norman Lockyer, F.R.S.

and Ireland is far from sufficient for the vigorous prosecution of Physical Research.

II. It is universally admitted that scientific investigation is productive of enormous advantages to the community at large; but these advantages cannot be duly reaped without largely extending and systematizing Physical Research. Though of opinion that greatly increased facilities are undoubtedly required, your Committee do not consider it expedient that they should attempt to define categorically how these facilities should be provided, for the following reason:—

Any scheme of scientific extension should be based on a full and accurate knowledge of the amount of aid now given to science, of the sources from which that aid is derived, and of the functions performed by individuals and institutions receiving such aid. Your Committee have found it impossible, with the means and powers at their command, to acquire this knowledge. A formal inquiry, including the inspection of records to which your Committee have not access, and the examination of witnesses whom they are not empowered to summon, alone can elicit the information that is required; and, as the whole question of the relation of the State to Science, at present in a very unsettled and unsatisfactory position, is involved, they urge that a Royal Commission alone is competent to deal with the subject.

Your Committee hold that this inquiry is of a character sufficiently important to the nation, and sufficiently wide in its scope, to demand the use of the most ample and most powerful machinery that can be brought to bear upon it.

Your Committee therefore submit, as the substance of their Report, the recommendation that the full influence of the British Association for the Advancement of Science should at once be exerted to obtain the appointment of a Royal Commission to consider—

1. The character and value of existing institutions and facilities for scientific investigation, and the amount of time and money devoted to such purposes.
2. What modifications or augmentations of the means and facilities that are at present available for the maintenance and extension of science are requisite; and,
3. In what manner these can be best supplied.

On Emission, Absorption, and Reflection of Obscure Heat.

By Prof. MAGNUS*.

THERE WAS a time when heat was considered to be very different from light. Now, however, we are persuaded that the only difference between them is the length of the waves by which they are produced and propagated. Therefore I thought that the well-known laws of the radiation and absorption of light must also exist for heat. I followed in these thoughts Mr. Balfour Stewart, who, ten years ago, and several years before Kirchhoff and Bunsen had propounded their theory, published a paper in which he developed nearly the same ideas for heat as these philosophers did for light.

I will endeavour to give some of the results at which I arrived; but

* A communication ordered to be printed *in extenso* among the Reports.

before doing this, I must mention that for these experiments it was necessary to obtain the rays from the body examined unmixed with those of the flame or of any substance by which the body is heated. I succeeded in this by making use of a stream of heated air in which the body was suspended.

I found that different substances heated to 150°C . emit different kinds of rays; some only one kind, or waves of one length, and others waves of many different lengths. To the first class belongs pure Rock-salt. There is an analogy between the heat emitted by this body and the light produced by its vapours, or rather of the Sodium it contains. The light from this substance gives only one line in the spectrum, and the heat also is only of one wave-length. It is monothermic, as its vapour is monochromatic.

Rock-salt absorbs the heat given out by Rock-salt, while it absorbs almost none of that given out by other substances.

There is another crystallized substance, the chloride of potassium, called Sylvin, very like rock-salt in its behaviour; but it is not monothermic, because it absorbs the heat from different substances, not in a very high degree, but to a greater extent than rock-salt does.

If our eyes would allow us to see the dark heat as we see light, and we could project a spectrum of the heat of rock-salt, we should see but one line. But in making use of the heat emitted by chloride of potassium a longer space would be illuminated, but not so long as from lampblack or from a flame.

Here also is an analogy between the heat and light given off by chloride of potassium.

I then made experiments on the reflection of heat, and I found that Silver, Glass, Rock-salt, Sylvin, and Fluorspar reflect nearly the same quantities of heat coming from a flame, from Lampblack, Glass, or from other substances. But of the heat from Rock-salt, the Fluorspar reflects five times as much as of that from other substances. Of the heat from Sylvin the Fluorspar reflects three times as much.

It follows from these experiments that if obscure heat were visible, and if Rock-salt were used as the source of heat, we should see the Fluorspar brighter than all other bodies, as far as I know at present. With Sylvin as the source of heat we should see the Fluorspar bright, but not so bright as in the heat from Rock-salt.

Although invisible to the eye there are millions of rays of heat passing between different substances, being partly absorbed and partly reflected; and although we are surrounded by these motions, we cannot observe them but by special experiments.

The analogy between light and heat seems to me to be complete.

Report on Observations of Luminous Meteors, 1868–69. By a Committee, consisting of JAMES GLAISHER, F.R.S., of the Royal Observatory, Greenwich, President of the Royal Microscopical and Meteorological Societies, ROBERT P. GREG, F.G.S., F.R.A.S., E. W. BRAYLEY, F.R.S., ALEXANDER S. HERSCHEL, F.R.A.S., and CHARLES BROOKE, F.R.S., Secretary to the Meteorological Society.

THE Catalogue of the Tenth Report of this Committee contains the results of assiduous observations of shooting-stars, directed principally to the periodical dates when shower-meteors are usually expected to occur. Many observations are, besides, recorded from the published accounts, and privately communicated descriptions of observers on the large meteors which have appeared with more than ordinary frequency during the interval of the year elapsed since the presentation of the last Report.

The general insufficiency of some of the observations, for the purpose of determining approximately the real distance of the meteors, is not greater than must always be expected to arise, when a due allowance is made for the unprepared condition of observers at the moment of the appearance of such unusually large and brilliant meteors as have during the past year been seen in some abundance. The comparison of some of the accounts contained in the present list has, nevertheless, led to satisfactory conclusions regarding the real height and course of some of the splendid fireballs recorded in the paragraphs of this Report. Among those which principally appear to have afforded elements of strict mathematical calculation may be mentioned the observations made in France on the large fireball of the 5th of September, and those at Cambridge and in Paris on the detonating meteor of the 31st of May last.

Some interesting communications on the same subject, bearing especially on the extent, velocity, and direction of the currents observed to exist in the loftiest regions of the atmosphere, are included with the heights of certain persistent meteor-streaks determined by Professor Newton, in the United States, on the 14th of November last. These observations, with the last-mentioned descriptions of bright meteors seen at the same time in England and on the Continent, are contained in the first Appendix of the Report.

The occurrences of new aërolites and of other large meteors are described in detail, and frequent minor notices of similar appearances from foreign sources are placed in the second Appendix; to which is added a Catalogue of recent fireballs, completing up to the present time the very comprehensive list of such appearances which, since their first Report, Mr. Greg has continued with unflagging industry to collect for the Committee.

The observations reported in the next Appendix show that the periodical star-shower of August, in the past and present years, has been made the subject of increasing attention in England and on the Continent. The systematic observation of the rate of frequency, time of maximum, and apparent position of the radiant-point has not yet cleared up some of the perplexities which surround the exhibition of this well-known but not yet thoroughly explained phenomenon. The possible prevalence of several maxima, and an apparent oscillation of the radiant-point in successive years between tolerably wide limits in the constellations Perseus and Cassiopeia, are features of this meteoric current which especially call for further investigation. The characteristic appearances of the meteors, both as to magnitudes and to the abun-

dance and duration of their luminous streaks, are also points of principal and recurring interest.

Owing to the exceptionally overcast state of the sky in England during the whole of the winter and summer months of the past year, the number of observations of the ordinary shower-meteors of October, December, January, and April last have not only been unusually deficient, but observers in England were unfortunately deprived of more than partial views of the great star-shower of the 14th of November last. Several interesting notices of the bright display, from transatlantic and continental stations, will, however, be found in the third Appendix; and that and previous reappearances of the star-shower are further illustrated by papers in the fourth Appendix of the Report. Some insight into the physical structure of the November meteoric cloud has, it will thus be seen, been derived from the simultaneous observations of its recent principal displays at places as far apart in longitude as Shanghai, Calcutta, Greenwich, and the observatories of the United States. It appears that the central and most compact portion of the stream was twice encountered in the years 1866 and 1867, while in the years 1865 and 1868 respectively, two outlying currents of greater width, but of less considerable density, were crossed, one on either side of the central stream, and separated from it, the former in front of, and the latter behind its margin, by an equally broad well-defined space comparatively devoid of meteors. This curious circumstance, first pointed out by Mr. Marsh, of Philadelphia, is drawn from observations at the conclusion of Appendix IV.

A review of several important papers published, and received by the Committee, during the past year, occupies the whole of the fourth and last Appendix of the Catalogue. The consideration now generally bestowed upon observations of luminous meteors is sufficiently rewarded by the occasional perusal of such papers of eminent scientific interest in the special branches of *aërolitic* and meteoric astronomy; while the present zeal of observers is evinced by their association together in France and Italy to record in a regular and systematic form, under the direction, at Metz, of a luminous meteor committee like that of the British Association, the transitory phenomena of meteors and falling-stars. In consequence of the combination of observers to observe shooting-stars together on stated nights, it cannot be doubted that a great accession to the present state of knowledge of this class of bodies will thus, in the course of a few years, be obtained. The star-showers of April last, which, on account of the unfavourable state of the weather, were unperceived in this country, were yet conspicuously seen at Moncalieri near Turin, and at Urbino, and the radiant-points of these meteoric epochs of the 10th, 20th, and 30th of April, already previously established by the British Association, received an unexpected confirmation.

With the object of furthering the views, and assisting the progress of meteoric science in its most highly productive sphere of observation, the Committee, in presenting this their Tenth Annual Report, express the hope that the same success may continue to attend their future efforts which has rewarded them in the first period of their existence, and which was originally bequeathed to them by the great and talented author of the annual Reports to the British Association on observations of luminous meteors, when, in the year 1860, after compiling the present Catalogue alone and presenting it unassisted to the British Association for fifteen years, he for the first time placed the preparation of these Reports, and the annual collection of observations of luminous meteors, in the hands of a committee.

A CATALOGUE OF OBSERVATIONS

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1862. Nov. 27	h m s 5 52 p.m.	Between N. Foreland and Broadstairs.	Apparent diameter about one-fifth that of the full moon.	Rather deep blue.	6 seconds ...	First appeared very close to Mars. Passed about 6' under the moon and disappeared under Altair at an altitude of about 10' above the horizon.
1866. Sept. 17	10 22 p.m.	Birmingham ...	= 3rd mag.*	Blue	0.5 second ...	From η Draconis $\alpha = \delta =$ to $224^\circ + 48^\circ$ From $\frac{1}{2}$ (ζ, ω) Draconis to α Cygni.
	17 10 22 30 p.m.	Ibid	= 3rd mag.*	Blue	0.5 second ...	From $\frac{1}{2}$ (ζ, ω) Draconis to α Cygni.
	17 10 55 p.m.	Ibid	= 1st mag.* , then = 4.	Deep yellow and ruby.	2.5 seconds ...	From α Persei to δ Aurigæ.
	17 11 0 p.m.	Ibid	= 1st mag.*	Yellow	2 seconds	$\alpha = \delta =$ From $9^\circ - 18^\circ$ to $348 - 27$
	17 11 22 p.m.	Ibid	= 3rd mag.*	Blue	1 second	$\alpha = \delta =$ From $90^\circ + 27^\circ$ to ϵ Geminorum.
Oct. 28	10 46 p.m.	Ibid	= 1st mag.*	Blue	0.75 second ...	$\alpha = \delta =$ From $346^\circ - 5^\circ$ to $333 - 16$
Nov. 18	5 40 p.m.	Wadhurst (Sussex).	Splendid meteor ...			Appeared near the moon.
1867. Aug. 19	9 27 p.m.	Birmingham ...	= 2nd mag.*	Red	1.5 second ...	$\alpha = \delta =$ From $49^\circ + 48^\circ$ to α Pegasi.
	20 9 15 p.m.	Ibid	= 3rd mag.*	Blue	0.5 second ...	From ζ Aquilæ to θ Serpentis.
	21 11 30 p.m.	Ibid	= 3rd mag.*	Blue	0.5 second ...	From κ Boötis to α Lyrae.
	21 11 52 p.m.	Ibid	= Sirius	White	1 second	From ϵ Capricorni to λ Piscis Australis.
	27 11 3 p.m.	Ibid	= 1st mag.*	White	0.75 second ...	$\alpha = \delta =$ From $305^\circ + 20^\circ$ to $291 - 8$
	27 11 3 p.m.	Ibid	= 3rd mag.*	Blue	1 second	Through the body-stars of Camelopardus.

OF LUMINOUS METEORS.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
The nucleus was followed by a flame-coloured tail about 2° long. It was twice nearly extinguished in its course, but both times regained its luminosity.		Inclining towards the earth.	The horizon itself was invisible.	James Chapman.
.....		From Radiant R ₁ , 2	.....	W. H. Wood.
.....		From Radiant V	.....	Id.
Left a tail 12° long for one second. Ruby-coloured sparks issued from the meteor.		From Radiant R ₁ , 2	Beautiful colours.....	Id.
Left a train for 1½ second		From Radiant U	.....	Id.
.....		From Radiant T ₂ , 3, 4	Meteors five or six per hour.	Id.
.....		From Radiant R ₃	.....	Id.
Did not leave much train			Though the moon was brilliant, the meteor was yet very bright; even brighter than those of November 14th, 1866.	Communicated by A.S. Herschel.
Left a streak		From Radiant ε Cassiopeæ.	.....	W. H. Wood.
.....		From Radiant ε Cassiopeæ.	.....	Id.
.....		From Radiant M G ₅	.....	Id.
Left a streak		From Radiant Q G	.....	Id.
.....		From Radiant ε Cassiopeæ.	This meteor nearly simultaneous with the next.	Id.
.....	15°	From Radiant ε Cassiopeæ.	.....	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1867. h m Aug. 27 11 20 p.m.		Birmingham ...	= 3rd mag.*	Blue	0.5 second ...	From α Delphini α Pegasi.
27 11 20 p.m.		Ibid	= Sirius	Orange colour	1.5 second ...	$\alpha = \delta =$ From $329^\circ - 13'$ to $310 - 19$
27 11 35 p.m.		Ibid	= 2nd mag.*	Blue	0.5 second ...	From ϵ to δ Aqu
27 12 0 p.m.		Ibid	= 3rd mag.*	Blue	2 seconds.....	$\alpha = \delta =$ From $336^\circ - 21'$ to $348 - 18$
28 12 1 a.m.		Ibid	= 2nd mag.*	Blue	1.5 second ...	From α Aquarii α Equulei.
28 12 7 a.m.		Ibid	= 1st mag.*	Blue	1 second	From ϵ to β Ceti
28 12 18 a.m.		Ibid	= 1st mag.*	Blue	0.5 second ...	From π Andromedæ to γ Pegasi.
Sept. 3 10 40 p.m.		Ibid	= 3rd mag.*	Blue	1 sec.; slow motion.	$\alpha = \delta =$ From $335^\circ + 18'$ to $350 + 15$
3 10 42 p.m.		Ibid	> 1st mag.*	White	0.3 sec.; rapid	From α Triang $\alpha = \delta =$ to $40^\circ + 32'$
3 10 45 p.m.		Ibid	= 1st mag.*	Yellow	0.5 second ...	$\alpha = \delta =$ From $347^\circ - 7'$ to $353 - 18$
3 10 50 p.m.		Ibid	= 3rd mag.*	Blue	0.5 second ...	From α Delphini α Equulei.
22 10 15 p.m.		Ibid	= 3rd mag.*	Blue	1.5 second ...	$\alpha = \delta =$ From $0^\circ - 6'$ to $335 14$
24 10 20 p.m.		Ibid	= 2nd mag.*	Blue	0.75 second ...	$\alpha = \delta =$ From $121^\circ + 61'$ to $196 + 71$
28 9 20 p.m.		Ibid	> 1st mag.*	Blue, then white.	0.5 second ...	From α Lyrae to Ophiuchi.
Oct. 3 10 3 p.m.		Ackworth, Pontefract (Yorkshire).	= 2nd mag.*	Bright white..	2 secs.; rapid	$\alpha = \delta =$ From $12^\circ + 12'$ to $13 + 8$
8 10 10 p.m.		Birmingham ...	> 1st mag.*	Deep blue ...	0.75 second ...	$\alpha = \delta =$ From $298^\circ + 30'$ to σ Aquilæ.
18 9 57 p.m.		Ackworth, Pontefract (Yorkshire).	= 1st mag.*	Yellowish ...	3 secs.; slow motion.	$\alpha = \delta =$ From $70^\circ + 50'$ to $310 + 60$ Rather north the zenith.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
.....		From Radiant $Q_3 a$	This meteor followed at a brief interval by the next.	W. H. Wood.
.....		From Radiant R_3	Average rate of fre- quency 12 per hour; fine clear night.	Id.
.....		From Radiant V	Commencement of this meteor - shower not seen; but meteors came in groups be- tween 9 ^h 30 ^m and 11 ^h p.m., with nearly a quarter of an hour's interval of repose.	Id.
.....		From Radiant ζ Capri- corni.	.....	Id.
.....		From Radiant β Ceti ...	.....	Id.
.....		From Radiant B_1 .....	.....	Id.
.....		From Radiant ϵ Cassio- peæ.	.....	Id.
.....		From Radiant Q_8	Path curved laterally ...	Id.
.....		From Radiant T_1	Meteors four in ten minutes. Clouds pre- vented further obser- vations.	Id.
.....		From Radiant B_3	A severe thunderstorm..	Id.
.....		From Radiant B_5 .....	.....	Id.
.....		Vertically down. From Radiant R G.	The last 10° of its path curved.	Id.
Left a train for 2 seconds		From Radiant G	One meteor in an hour; fine night.	Id.
Left a streak		From Radiant ϵ Cassio- peæ.	Fine nights on the 10th, 19th, and 25th; no meteors seen. Night of the 28th overcast.	Id.
Brightest in the middle of its course.	4½° .....		.....	J. E. Clark.
Left a smoky streak		From Radiant B_2 .....	.....	W. H. Wood.
Left a fine train which did not last.	50°	Directed from Capella...	Two small meteors about 9 o'clock.	J. E. Clark.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1867. Oct. 13	h m s 9 57 3 p.m.	Ackworth, Pontefract (Yorkshire).	= 1st mag.*.....	Yellowish ...	1½ sec.; slow	$\alpha = \delta =$ From $60^{\circ} + 50^{\circ}$ to $35 + 47$
18	10 16 p.m.	Ibid	= 2nd mag.*	Red	2 secs.; very slow.	From $296.5^{\circ} + 1^{\circ}$ to $289 - 3$
19	10 11 p.m.	Ibid	= Sirius	Red	2 secs.; very slow.	Near Rigel
19	10 20 p.m.	Ibid	= 1st mag.*.....	Red	2½ seconds ...	Disappeared very near Jupiter.
19	10 33 p.m.	Ibid	= 1st mag.*	White	0.75 second ...	In the south; on the left of Jupiter.
20	10 4 p.m.	Ibid	= 2½ mag.*	Red	3½ secs.; very slow.	In the south; on the left of Jupiter.
20	10 14 p.m.	Ibid	= 3rd mag.*	White	1.5 second ...	In the direction to- wards and near Jupiter.
20	11 17 p.m.	Birmingham ...	= 3rd mag.*	Blue	0.5 second ...	From τ to ϵ Pe- gasi.
20	11 20 p.m.	Ibid	= 1st mag.*.....	Orange colour	0.75 second ...	From α Orionis, $\frac{3}{4}$ of the way to α Tauri.
Nov. 3	About 9 p.m.	Ackworth, Pontefract (Yorkshire).	.....	.....	.....	.....
16	6 10 to 6 40 p.m.	Ibid	= 1st to 4th mag.* .....	.....	.....	In the E.
17	8 37 p.m.	Ibid	= 1st mag.*.....	White	1.5 second ...	$\alpha = \delta =$ From $295^{\circ} + 48^{\circ}$ to $283 + 37$
21	8 20 p.m.	Ibid	Half as bright again as 24.	Yellowish ...	1 sec.; rapid motion.	First appeared near η Pegasi, and disappeared in clouds near Ju- piter.

Appearance ; Train, if any, and its Duration.	Length of Path.	Direction ; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left no streak		From Capella, towards S.W.	Another meteor at 10 ^h 12 ^m p.m.	J. E. Clark.
Left a fine thin train	11°		Very distinct. Another meteor appeared at 10 ^h 25 ^m p.m.	Id.
Left a fine train of a green- ish tinge.	10°		Very oscillating motion	Id.
Left a red train of varying brightness.	15°		Two meteors about si- multaneous with this.	Id.
Left a dull train	5°		From the same Radiant as the last.	Id.
Left a slight train	10°		Almost disappeared during its course.	Id.
Left a slight train	10°		Opposed in its direction to the last. Another at 10 ^h 16 ^m p.m.	Id.
		From Radiant R ₁ , 2		W. H. Wood.
		From Radiant S ₁ (?) ...		Id.
			On this night and the following five meteors were observed.	J. E. Clark.
			Eight meteors were seen	Id.
	14°		Fluctuated in its course. Another meteor ap- peared near Aquila at 8 ^h 28 ^m p.m.	Id.
Left a bright train for 3 seconds.	40°	Moved along a line parallel to β , α Pe- gasi. 	The observer's back Id. being turned to the meteor, his attention was drawn to it by the reflected light, and its course was marked by the per- sistent streak.	

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1867. Nov. 21	h m s About 8 25 p.m.	Ackworth, Pontefract (Yorkshire).	=3rd mag.*	White	0.5 second ...	$\alpha = \delta =$ From $272^{\circ} + 38^{\circ}$ to $267 + 39$
21	10 8 p.m.	Ibid	=2nd mag.*	White	Almost instantaneous.	About $1\frac{1}{2}^{\circ}$ to right of Rigel.
22	About 7 20 p.m.	Ibid	=3rd mag.*	White	2 seconds.....	2° to left of α Centauri [?].
26	10 2 p.m.	Ibid	About 4' apparent diameter.	Brilliant white	3 seconds.....	$\alpha = \delta =$ From about $48^{\circ} - 3^{\circ}$ to about $65 - 5$
26	10 34 p.m.	Ibid	=3rd mag.*	Red	1.5 second ...	$\alpha = \delta =$ From $55^{\circ} - 13^{\circ}$ to $55 - 20$
27	8 50 p.m.	Ibid	=2nd mag.*	White	0.25 sec.; rapid	First appeared almost in the zenith, near α Persei.
28	7 17 p.m.	Ibid	=3rd mag.*	Red	0.5 sec.; rapid	Centre of path midway between the head of Aries and the Pleiades.
1868. Feb. 4	7 33 p.m.	Ibid	=4.....	White	1 second	In the W.S.W.; from about 30° to 22° above the horizon.
July 14	10 50 p.m.	Street (Somerset).	=1st or 2nd mag.* .....	.....	.....	In Draco
15	10 35 p.m.	Ibid	=2nd mag.*	White .....	.....	Commenced at θ Draconis.
30	5 55 50 a.m. (local time).	Italaya Observatory, Brazil.	Apparent diameter about 43' of arc.	Colour of the electric light.	17 seconds ...	Commenced 30° from the meridian in the east, which it crossed at S. Decl. 65° (Zen. dist. $42^{\circ} 32'$), and disappeared behind a hill $50^{\circ} 15'$ west of south.
Aug. 10	10 51 p.m. (local time).	Rome	Large meteor .....	.....	.....	From the head of Boötes, across the hand of Hercules to the hand of Ophiuchus.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Like a small molten drop falling out of Vega Lyrae.	11°	Perpendicular to the horizon. 	Ten meteors seen from 8 ^h to 8 ^h 30 ^m p.m.	J. E. Clark.
.....	3° .....		.....	Id.
At first scarcely visible ...	2° .....	.....	.....	Id.
The nucleus was followed by a short bright red tail, and proceeded by three successive jerks, apparently gradually fading.	23°	 	Seen through light clouds, which obscured the smaller stars. A large halo of light surrounded the meteor, which sensibly illuminated the landscape.	Id.
Gradually faded out	7°	Almost perpendicularly down.	.....	Id.
.....	3°	Moving towards Cassiopeia.	Another meteor appeared above Orion at 8 ^h 45 ^m p.m.	Id.
.....	7°	Directed from α Persei	.....	Id.
Faded gradually from sight	10° .....		.....	Id.
Two meteors appeared about the same time.	.....	.....	.....	Id.
.....	10°	Towards Corona Borealis.	.....	Id.
Globular, followed by a train 9° long, oval and spreading at the end. Both tail and nucleus were as bright as the electric light, emitting luminous drops and silvery sparks.	Length of visible path 77° 41'.	[? Apparent] motion inclined 17° 40' to the ecliptic; retrograde.	At the appearance of the meteor, the compass-needle oscillated 15° from the north towards the west; six minutes later, a detonation was heard in the south-west.	'Anglo-Brazilian Times,' August 7th, 1868. Dr. F. Massena and Messrs. Arsenio and Veija.
Like a large meteor of the November shower.	.....	.....	Seen also at Civita Vecchia by Professor Pinelli.	Mme. Scarpellini, 'Annales de l'Observatoire de Bruxelles' for 1868-69, p. 164.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Aug. 15	h m 10 13 p.m.	Primrose Hill, London.	=1½ mag.*	White .....	.....	$\alpha = \delta =$ From 337° + 45° to 316 + 30
	15 10 36 p.m.	Ibid	=2nd mag.*	White .....	.....	From 23° + 43° to 360 + 20
	23 10 12 p.m.	Ibid	> 4	Bright orange, then fiery red.	2½ seconds; moved slowly.	From 310° + 44° to 335 + 34
	25 9 33 p.m.	Ibid	=3rd mag.*	White	Moved slowly	From 301° + 29° to 335 + 31
	25 10 7 p.m.	Ibid	=2nd mag.*	White .....	.....	From 328° + 32° to 345 + 29
	25 10 49 p.m.	Ibid	=3rd mag.*	White	Moved very swiftly.	From 11° + 87° to 245 + 33
	25 10 54 p.m.	Ibid	=2½ mag.* .....	.....	.....	From 30° + 65° to 126 + 61
	25 10 57 p.m.	Ibid	=1½ mag.*	Orange colour .....	.....	From 221° + 78° to 259 + 50
Sept. 5	Between 7 and 8 p.m.	Pic de Sancy, France.	Large meteor .....	.....	Between 4 and 5 seconds.	Disappeared ex- actly at β Ursæ Majoris.
	5 About 8 p.m. (Paris time)	Clermont, France	Large meteor .....	.....	12 seconds ...	Started from the mountains of Fo- rez, in the east; passed north of Clermont, and disappeared be- fore reaching the mountains of Puy de Dôme, in the west.
	5 8 18 p.m. (Paris time)	Geneva.....	Many times larger than Jupiter.	Colourless, or reddish.	Moved slowly; about 20° or 30° per sec.	The meteor passed close by η Ursæ Majoris.
	5 A few mi- nutes be- fore 8 30 p.m., Tu- rin time.	Aosta, Piedmont	Many times brighter than a 1st mag.*	Brilliant white; with yellowish or pinkish tinge.	Moved slowly, as if resisted in its flight.	Appeared in the east; traversed the whole visible horizon of the valley of Aosta, towards the W.N.W., and disappeared be- hind the hills in that direction.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a long tapering streak .....	.....	From Radiant, near β Camelopardi.	This and the next very much alike. One more meteor from α Aquilæ.	T. Crumplen.
Left a streak like the last .....	.....	From the same Radiant as the last.	.....	Id.
Left a train on two-thirds of its course. Threw off a few small sparks.	.....	.....	A splendid meteor with perceptible disk.	Id.
Left a slight train .....	.....	Downwards to left. From Radiant, near β Cygni.	.....	Id.
.....	10°	From the same Radiant as the last.	.....	Id.
Left a faint train which faded instantly.	.....	.....	.....	Id.
.....	.....	.....	Imperfect view	Id.
Left a train on about half its course.	25° .....	.....	Very fine meteor; colour very marked.	Id.
The whole length of the meteor from the head to the point of the rocket-like tail 10°. It neither changed colour nor form during its passage, and went suddenly out.	Not less than 45°.	Direction exactly parallel to the horizon.	The time of its appearance was about half an hour before the moon rose; a very imposing meteor both for magnitude and steadiness of movement. Another large meteor was seen at Ashford (Kent) on the same evening (The Times, Sept. 10).	B. F. Smith; 'The Times,' Sept. 8th, 1868.
The meteor gradually decreased in volume as if by the loss of sparks, which remained without descending to the earth along the bright luminous streak. This remained visible on the whole of its course for some time.	.....	From due E. to W.	A most brilliant meteor. No sound was heard after its disappearance. (See a calculation of its path in Appendix I.)	'Comptes Rendus,' Sept. 21st, 1868.
Drew a long tail, but left no distinct streak on its course. It did not burst, but disappeared gradually in the distance.	.....	Its path was horizontal	The commencement not seen, but the light as it passed caught the observer's eye.	E. Jones.
Followed by a long tapering tail of smaller width than the nucleus, and losing itself at last in a faintly luminous vapour.	.....	Horizontal	At the same time and in the same direction (from E. to N.W.) a meteor of the same appearance was observed at Moncalieri. A splendid meteor was also observed at the same time (9 ^h p.m., Roman time) at Florence.	F. Denza; 'Stelle Cadenti del Periodo di Agosto Osservati in Piemonte nel 1868,' p. 55.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Sept. 10	h m 10 11 p.m.	Tooting, London	=3rd mag.*	White	Very brief ...	$\alpha = \delta =$ From $222^{\circ} + 40^{\circ}$ to $226 + 28$
	10 10 33 p.m.	Birmingham ...	=2nd mag.*	Blue	0.5 second ...	From ρ Pegasi to Aquari.
	10 10 50 p.m.	Tooting, London	=3rd mag.*	White	$\frac{1}{2}$ second	$\alpha = \delta =$ From $180^{\circ} + 70^{\circ}$ to $188 + 57$
	10 10 51 p.m.	Birmingham ...	=1st mag.*	Yellow	0.25 second ...	From $270^{\circ} + 29^{\circ}$ to $270 + 10$
	10 11 1 p.m.	Ibid	=3rd mag.*	Reddish	0.5 second ...	From $325^{\circ} - 2^{\circ}$ to $321 - 11$
	10 11 16 p.m.	Ibid	=3rd mag.*	Blue	1 second	From $270^{\circ} + 10^{\circ}$ to $267 + 5$
	12 About 11 0 p.m.	Pitlochrie (Perthshire).	=1st mag.*	Reddish white	2 seconds ...	After pursuing one- third of its course it passed over α Lyrae.
	12 About 11 0 p.m.	Ibid	=2nd mag.*	White	0.75 second ...	Close to L Came- lopardi.
	13 Between 9 15 and 10 5 p.m.	Ibid	=3rd mag.*	Reddish	0.5 second ...	Commenced near α Persei.
	13 Between 9 15 and 10 5 p.m.	Ibid	=3rd mag.*	Dull reddish..	1 second	Near δ Boötis
	13 Between 9 15 and 10 5 p.m.	Ibid	=2nd mag.*	White	0.75 second ...	Commenced near γ Andromedæ.
	13 Between 9 15 and 10 5 p.m.	Ibid	=1 $\frac{1}{2}$ mag.*	White	0.75 second ...	Commenced near and below α An- dromedæ.
	13 10 31 p.m.	Birmingham ...	=2nd mag.*	Blue	0.5 second ...	Midway between γ Pegasi and γ Arietis.
	14 About 10 30 p.m.	Pitlochrie (Perthshire).	=1 $\frac{1}{2}$ mag.*	White	Slow motion ; 2 seconds.	Commenced in Custos Messium. Disappeared 5° below α Persei.
	14 About 10 30 p.m.	Ibid	=3rd mag.*	Dull .....	.....	Commenced in the square of Came- lopardus.
	23 9 26 p.m.	Ackworth, Pontefract (Yorkshire).	=3rd mag.*	White	0.3 second ...	$\alpha = \delta =$ From $280^{\circ} + 87^{\circ}$ to $245 + 78$
	26 3 26 a.m.	Ibid	=1st mag.*	White	0.2 second ...	From $52^{\circ} + 10^{\circ}$ to $48 + 9$
	26 3 27 a.m.	Ibid	=2nd mag.*	White	0.3 second ...	Near ρ Eridani ...

Appearance ; Train, if any, and its Duration.	Length of Path.	Direction ; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a streak which in- stantly disappeared.	.....	Slightly curved path ...	Sky clear; no moon; careful observation.	W. Jackson.
Nucleus followed by an adhering tail.	.....	From Radiant $T_{2,3,4}$...	Fine clear night	W. H. Wood.
Left a streak which was immediately extinguished.	.....	.....	Stars brilliant; carefully observed.	W. Jackson.
.....	.....	From Radiant $N_{12,13}$ ...	.....	W. H. Wood.
.....	.....	From Radiant B_5 .....	.....	Id.
.....	.....	From Radiant B_5 .....	.....	W. Jackson.
.....	More than 25° .	Directed from α Cygni	.....	R. P. Greg.
.....	About $\frac{1}{2}^\circ$...	Directed towards Ursa Major.	.....	Id.
Nucleus phosphorescent and trained.	.....	.....	.....	Id.
Like a small nebulous body	5°	Directed from Ursa Minor.	.....	Id.
Left a streak	7°	Directed towards α Per- sei.	From Radiant T_2	Id.
.....	.....	Fell vertically	From Radiant E in La- certa.	Id.
.....	More than 10° .	Directed from Radiant QG or T_1.	.....	Id.
.....	12°	Directed from Radiant N 15 (?).	.....	Id.
.....	10°	Fell vertically, nearly from the direction of Cygnus.	.....	Id.
.....	10°			J. E. Clark.
Left a train which lasted 3 or 4 seconds.	$4\frac{1}{2}^\circ$	 Directed from α Tauri...	.....	Id.
Left a train for 5 seconds	3° or 4° ...	 	Apparently directed from the same Ra- diant-point as the last meteor.	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Sept. 29	h m Evening ...	Troy, U. S. America.	Large meteor	Bright rose and red.	10 seconds ...	First appeared at an altitude of about 50° in the N.E.
Oct. 7	About 10 15 p.m. (Paristime).	Chirac, Lozère, France.	As bright as the full moon.	Like moon-light; bluish.	About 3 secs.	Disappeared near Ursa Minor.
7	At night ...	Liskeard (Cornwall).	20' or 30' in diameter.	Red and blue.....	.....	.....
7	About 11 30 p.m.	Sandwich (Kent).	Large meteor .....	.....	.....	.....
7	About 11 45 p.m.	Leytonstone ...	Large meteor .....	.....	3 or 4 seconds	It started from the centre of the heavens and took a southerly direction.
7	About 11 45 p.m.	Walworth, London.	Large meteor	Purple and red .....	.....	Descended to the right of the cluster of stars known as Cassiopeia's Chair.
7	11 48 p.m.	Wolverhampton	About the apparent size of full moon.	Colours of the train orange, yellow, and blue.	.....	Disappeared a few degrees above the northern horizon.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Followed by a very brilliant train. When half way on its course it exploded and threw out a great quantity of brilliant white sparks, the meteor still pursuing its course.	Length of the bright streak 30°.	Inclined to the horizon at an angle of between 70° and 80°.	A magnificent meteor; seen by many observers.	'The Troy Whig,' Oct. 1st, 1868.
Left a train of brilliant sparks in the form of an elongated cone, with its base at Ursa Minor.	.....	From S. to N.	The sudden flash of the light was like that of the full moon emerging from behind a cloud. The meteor itself not seen. No detonation heard. Time certainly before 10 ^h 30 ^m p.m.	Abbé Trueize and Abbé Boiral; 'Les Mondes,' 2nd ser., vol. xviii, p. 332.
At first an ordinary shooting-star, expanding almost instantaneously to a deep red ball; followed by a stream of vivid red light, pale bluish near the ball, 1° wide, and 20° in length. Before disappearing, the ball became bright blue, and ultimately burst, emitting numerous luminous fragments, which were instantly extinguished.	.....	.....	.....	'The Times,' Oct. 13th, 1868.
Surprisingly grand and brilliant appearance.	.....	From S. to N.	The heavens appeared for a moment to be a mass of fire.	'Daily Telegraph,' Oct. 9th.
A meteor of remarkable brilliancy, which disappeared suddenly.	.....	From N. to S. [?]	The observer's attention was first drawn to the meteor by an unusual and startling light.	W. H. L. (Ibid).
.....	.....	.....	The night was very fine and clear, and the meteor cast an immense glare around. Doubtless the largest meteor ever seen.	H. R. (Ibid).
At first it was just like a star, and in its course it increased in a startling manner, until at last it reached the apparent size of the moon and exploded, scattering rays of light in all directions.	About 15° or 20°.	From nearly S. to N. ...	No meteor seen on the 14th of Nov. 1866 was equal to it in magnitude. The light with which objects were illumined was sufficient for the observer to have picked up a pin.	W. H. Wood; 'Midland Counties Express.'

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Oct. 7	h m s About 11 50 p.m.	Brighton (Sussex).	Large meteor	Blue, then red .....	.....	.....
7	About 11 50 p.m.	Ramsgate (Kent).	A great fireball ...	The body white, and the tail of all the co- lours of the rainbow.	Lasted fully half a sec. ....	.....
7	About 11 50 p.m.	Wimbledon	Very large meteor	Red	Lasted several seconds. ....	.....
7	About 11 53 p.m.	Gordon Square, London.	Large meteor .....	.....	Lasted only a moment. ....	.....
7	About 11 55 p.m.	Sandown, Coast- guard Station, Isle of Wight.	At first a small fire- ball, gradually enlarging.	Various	2 or 3 seconds	First appeared at a considerable height above the horizon, due S.
7	11 59 54 p.m. (Paris time)	Belleville, Paris	Apparent diameter 30'.	At first white, then red. The frag- ments blue, yellow, and green.	7 seconds.....	Passed from south of α Cephei to north of η Ursæ Minoris, and on- wards between β and γ Ursæ Mi- noris.
7	About 12 0 p.m. (local time).	Angers, France...	Large meteor .....	.....	About 1.5 sec.	At an apparent altitude of 45° above the ho- rizon.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
The meteor itself not seen. The whole heavens seemed to be a mass of bright blue light followed immediately by a crimson hue of equal brilliancy.			The night was clear and frosty. The observer's attention was attracted by seeing the shadows of houses clearly thrown across the parade.	J. Fuller; 'Midland Counties Express.'
Rocket-like. A huge fire-ball with a flare of light like the comet seen at London some years since. It came silently and collapsed suddenly.		Descending towards the earth.	A very startling and imposing meteor. The whole sky seemed on fire. The flash of light illumined the interior of a room, at Bekesbourne, for 4 or 5 seconds.	Adam Dickson (Ibid).
A red ball emitting bright sparks, and followed by a flaming tail of great length.			The sky was clear. A vivid flash of bluish light illumined surrounding objects, overpowering the light of the moon, and casting actual shadows on the ground.	P. H. Lawrence; 'The Times,' Oct. 9th.
A sudden flash of light like lightning.			A beautiful starlight night. Seen also in several parts of the metropolis.	T. F. P. (Ibid).
It increased from a small ball, so as, in about two seconds, to obscure the moon; and burst into "variegated stars, springing from a body which assumed the shape of a huge luminous diving-bell; I can liken it to nothing else."		Descended in an easterly direction at an angle of about 45° towards the horizon.	During twenty-eight years' night-watching, and twelve more spent at sea, no meteor was before seen so large and brilliant.	John Burt; 'Daily Telegraph,' Oct. 10th.
Gradually increased until, on crossing Ursa Minor, it burst; the fragments spreading in a cone, 15° wide at the base, which was turned towards the earth. The meteor at the same time turned red, and the fragments were blue, yellow, and green.		From S. to N.	About 5 ^m 28 ^s after its disappearance, a loud explosion like the bursting of a mine in the neighbourhood was heard. The explosion was heard at Paris also by M. Le Bacilly [Ibid.]; and the meteor was seen at Düsseldorf, in Germany ['Les Mondes,' Second Series, xviii, 282].	Mons. Tremeschini; 'Comptes Rendus,' vol. lxvii, p. 771, Oct. 12th, 1868.
.....		Directed towards N.E....	An extremely bright meteor. No sound of an explosion was heard.	Mons. Morren (Ibid).

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Oct. 7	h m 12 0 p.m. (local time).	Tilloy les Conti, Somme, France.	Large meteor .....	.....	Very brief du- ration.	.....
	7 About 12 0 p.m. (local time).	Brussels, Belgium.	Large meteor; brighter than the moon.	.....	Very rapid ...	Disappeared in the N.W.
	10 11 10 p.m.	Birmingham ...	=2nd mag.*	Blue	1·5 second ...	$\alpha = \delta =$ From $0^{\circ} + 25^{\circ}$ to π Pegasi.
	10 11 17 p.m.	Ibid	=2nd mag.*	Dull white ...	2 seconds.....	$\alpha = \delta =$ From $4^{\circ} + 15^{\circ}$ to $358 + 15$
	11 12 45 a.m.	Ibid	=3rd mag.*	Blue	0·5 second ...	From ϕ_2 to β Ori- onis.
	11 12 52 a.m.	Ibid	=1st mag.*.....	Blue	0·2 second ...	$\alpha = \delta =$ From $75^{\circ} - 3^{\circ}$ to $74 - 7$
	11 1 0 a.m.	Ibid	=3rd mag *	Dull	0·5 second ...	$\alpha = \delta =$ From $60^{\circ} + 22^{\circ}$ to ϕ Aurigæ.
	11 7 1 p.m.	Ackworth, Pontefract (Yorkshire).	= γ	Red	1·5 sec.; very slow speed.	In the west; 10° above the hori- zon.
	15 9 22 p.m.	Tooting, London	About=3rd mag *	White	1 second	$\alpha = \delta =$ From $269^{\circ} + 30^{\circ}$ to $260 + 15$
	15 9 22 p.m.	Ibid	About=3rd mag.*	White	1 second	From $\frac{1}{2}(\alpha, \gamma)$ to $\frac{1}{2}$ (ϵ, ζ) Cygni.
	16 7 45 p.m.	Whitby (Yorkshire).	.....	.....	.....	From the star to the west [? α] of Andro- meda, to about the star Alge- rith [? α] in Taurus.
	17 12 1 a.m.	Birmingham ...	=3rd mag.*	Blue	0·5 second ...	From α Arietis to γ Pegasi.
	17 11 58 p.m.	Ibid	=3rd mag.*	Blue	0·5 second ...	From α_2 Orionis to ν Ceti.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
.....		Moving from E. to W...	The meteor cast a vivid light. A few moments after its disappearance there was heard a dull rumbling sound like that of a carriage rolling over a pavement.	Mons. Roze; 'Comptes Rendus,' vol. lxvii. p. 771, Oct. 12th, 1868.
Left a luminous streak on its course.		From S.E. to N.W....	The meteor threw a strong light. Seen also at Louvain, Liège, and Antwerp. According to the description at Paris, a violent explosion was heard a few minutes after its disappearance.	M. Marchal; 'Annales de l'Observatoire de Bruxelles' for 1868-69, p. 168.
.....		From Radiant, γ Ceti; or $R_1, 2$.	.....	W. H. Wood.
.....	Foreshortened course.	From Radiant $T_2, 3$.	.....	Id.
.....		From Radiant F_2.	.....	Id.
.....		From Radiant F_2.	.....	Id.
.....		From Radiant, γ Ceti or U.	.....	Id.
Left a slight streak.....	2°	.....	.....	J. E. Clark.
.....				
Left a streak which was extinguished at once.			This and the next two meteors were observed within a quarter of a minute of time.	W. Jackson.
Left a streak which lasted rather longer than that of the previous meteor.			No moon; stars very bright. Another minute meteor was seen, almost simultaneous and nearly in the same position, with this one.	Id.
.....		Directed from the Radiant O in Orion.	Two other meteors appeared at about 11 ^h p.m. from the bright star in the head of Petus [γ Ceti] to the head of Capricornus.	B. Livingstone; 'Daily News.'
.....		From Radiant R_3.	.....	W. H. Wood.
Left a streak		Directed from Radiant O	.....	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Oct. 17	h m s 10 5 p.m.	Ackworth, Pontefract (Yorkshire).	=1st mag.*	White	0.4 second ...	$\alpha = \delta =$ From $5^{\circ} - 17^{\circ}$ to $3 - 25$
17	10 50 p.m.	Somerton (Somersetshire).	About=1st mag.*	Bright white.....	.....	Disappeared near α Draconis.
18	12 8 a.m.	Birmingham ...	=3rd mag.*	Dull	0.5 second ..	From α to ζ Orionis.
18	12 9 a.m.	Ibid	> 1st mag.*	Green and red	1.5 sec.; slow speed.	$\alpha = \delta =$ From $55^{\circ} 0^{\circ}$ to γ Eridani.
18	12 23 a.m.	Ibid	=3rd mag.*	Reddish	0.5 second ...	From η Eridani $\alpha = \delta =$ to $47^{\circ} - 22^{\circ}$
18	12 23 30 a.m.	Ibid	=2nd mag.*	Blue	1 second	From β to θ Arietis
18	12 25 a.m.	Ibid	=1st mag.*	White	0.5 second ...	Shot from μ Eri- dani towards ϵ Leporis.
18	Between 9 15 and 9 35 p.m.	Tooting, London	About=3rd mag.*	Dull white ...	2 or 3 seconds	Just beyond and parallel with the south edge of the Milky Way; near the zenith.
18	9 54 p.m.	Birmingham ...	=3rd mag.*	Blue	1 second	From the Pleiades to α Trianguli.
18	About 10 0 p.m.	Tooting, London	Rather bright me- teor.	.....	Moved slowly	About halfway be- tween the 'Point- ers' (α, β Urse Majoris) and Ca- pella.
18	10 21 p.m.	Hornsey Road ...	Large meteor	Bright white....	4 to 6 seconds	It passed from a little south of δ Cassiopeiae to $\frac{1}{2}$ (γ, δ) Cygni and onwards $\frac{1}{2}$ of the way to the horizon.
18	10 26 p.m.	Tooting, London	=3rd mag.* .....	.....	$\frac{1}{2}$ second	From between Ple- iades and Alde- baran, a little nearer the former than the latter to $\frac{1}{2}$ (α, λ) Orionis.
18	10 47 p.m.	Ibid	=2nd mag.* ; larger and brighter than the last.	.....	1 second	It began under Ple- iades and ended between β and γ Arietis.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left no streak	8°			W. H. Wood.
Left a slight train which vanished immediately. ....	.....	From Radiant O		Id.
Left a streak .....	.....	From Radiant A ₁₈		Id.
.....	.....	From Radiant A _{14, 15}		Id.
.....	.....	From Radiant R _{1, 2}		Id.
.....	More than 10°.	From Radiant A ₁₈	Intercepted view.....	Id.
Passed slowly, giving out a broad but not very bright streak which was instantly extinguished.	60° .....	.....	Probably the same meteor as that seen at Hornsey Road at 10 ^h (? 9 ^h) 21 ^m p.m.; no moon; stars less bright than on the preceding night.	W. Jackson.
.....	.....	From Radiant O	One meteor in 15 minutes; sky hazy; overcast at 10 ^h 45 ^m p.m.	W. H. Wood.
.....	Its course curved thus—  about half a degree.	Almost horizontal, towards Ursa Major.	Between 10 ^h and 11 ^h p.m. three small meteors moved on a line a few degrees below and parallel to Pleiades and Jupiter, the second below the first, and the third below the second; all of the same length of course as that line.	W. Jackson.
Left a bright sheet of light on its course for 1 or 1½ minute. ....	.....	.....	Very fine meteor and fine streak.	T. Blunt; 'Daily News,' Oct. 1st.
.....	.....	.....		W. Jackson.
Left a bright streak which was at once extinguished. ....	.....	In a direction parallel to a line from η Tauri to α Arietis.	Careful observation.....	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. h m s Oct. 18 10 58 p.m.		Tooting, London	=3rd mag.*			Commenced a little below $\frac{1}{2}$ (β Aurigæ, Castor).
19 7 33 p.m.		Birmingham	=3rd mag.*	Pale blue	1 sec. ; slow speed.	From κ Cygni to γ Draconis.
19 10 52 p.m.		Ibid	=1st mag.*	Yellow	2 seconds	From $\frac{1}{2}$ (Pleiades, ζ Persei) $\alpha = \delta =$ to $0^\circ + 24^\circ$
19 11 7 p.m.		Ibid	=3rd mag.*	Blue	0.5 second	From $80^\circ + 90^\circ$ to the Pleiades.
19 11 10 p.m.		Ibid	=2nd mag.*	Blue	0.75 second	From ζ to β Tauri
19 11 21 p.m.		Ibid	=1st mag.*	Pale blue	0.5 second	From β to θ Aurigæ, and 2° further.
19 11 35 p.m.		Ibid	=2nd mag.*	Blue	0.5 second	Commenced at β Aurigæ.
19 11 40 p.m.		Ibid	=2nd mag.*	Yellow	1 second	$\alpha = \delta =$ From $94^\circ + 18^\circ$ to $96 + 20$
19 11 42 p.m.		Ibid	=2nd mag.*	Blue	0.5 second	From γ Orionis to σ Eridani.
19 11 42 30 p.m.		Ibid	=1st mag.*	Yellow	1 second	From ζ Tauri to ζ Persei.
19 11 48 p.m.		Ibid	=Sirius	White, orange, dull red.	4 seconds	From π_1 Orionis $\alpha = \delta =$ to $148^\circ + 80^\circ$
20 12 4 a.m.		Ibid	=2nd mag.*	Yellow	0.5 second	From ξ Ceti to α Piscium.
20 12 11 a.m.		Ibid	=3rd mag.*	Dull	0.25 second	Appeared at $\alpha = \delta =$ $85^\circ + 15^\circ$
20 12 12 a.m.		Ibid	=Sirius	White	1 second	From $120^\circ + 49^\circ$ to $139 + 45$
20 12 17 a.m.		Ibid	=2nd mag.*	Orange	0.5 second	From $105^\circ + 37^\circ$ to $129 + 51$
20 12 29 a.m.		Ibid	=1st mag.*	Orange	1 second	From θ Geminorum $\alpha = \delta =$ to $128^\circ + 56^\circ$
21 8 12 p.m.		Ibid	=3rd mag.*	Blue	0.5 second	Appeared at $\alpha = \delta =$ $20^\circ + 5^\circ$
21 9 25 p.m.		Tooting, London	=2nd mag.*	White	3 seconds	From near τ to $\frac{1}{2}$ (ζ , ϵ) Herculis.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
.....	.....	From the direction of α Orionis.	.....	W. Jackson.
.....	.....	From Radiant U, or $T_2, 3, 4$.	.....	W. H. Wood.
Left a green train 25° in length.	.....	From Radiant O	.....	Id.
.....	.....	From Radiant L H or O	.....	Id.
Left a streak	.....	From Radiant O	.....	Id.
.....	.....	From Radiant F_2	From $10^h 30^m$ to $11^h 30^m$ p.m. four meteors seen.	Id.
.....	20°	Towards Polaris, from Radiant O.	.....	Id.
Left a green streak	.....	From Radiant O	.....	Id.
.....	.....	From Radiant O	.....	Id.
Left a red streak	.....	From Radiant O	.....	Id.
Meteor showed two maxima and minima. Changed colour from white to red, nearly disappearing, and progressing some distance as a dull object. Left a streak of 30° in length, the first half green, the last red, which lasted five seconds.	The first 5° foreshortened; whole path 80° .	From an unknown southern Radiant.	.....	Id.
.....	.....	From Radiant G	.....	Id.
.....	10°	Directed towards π_1 Leonis.	From Radiant O	Id.
.....	.....	From Radiant F_2	.....	Id.
Left a red streak	.....	From Radiant O	For remarks on this meteoric shower see Appendix III.	Id.
Left a red streak	.....	From Radiant O	From $11^h 30^m$ p.m. to $12^h 30^m$ a.m. ten meteors.	Id.
.....	25°	Directed towards θ Ceti, from Radiant A_{10} .	The night of the 20th was overcast.	Id.
Left a broad streak for 2 seconds.	.....	.....	Moon set; sky clear; stars very bright; two faint lightning-flashes in the east between $9^h 45^m$ and 10^h p.m.	W. Jackson.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Oct. 21	h m s 9 49 p.m.	Tooting, London	= 3rd mag.*	White	1 second	From near γ Cygn to $\frac{1}{2}^{\circ}$ south of Lyra.
	21 10 33 and 10 52 p.m.	Primrose Hill, London.	= 4th mag.*	Like α Aurigæ	Steady speed..	In the N.E. or E..
	21 10 38 p.m.	Ackworth, Pontefract (Yorkshire).	= 2nd mag.*	White	0.5 second ...	$\alpha = \delta =$ From $322^{\circ} + 12^{\circ}$ to $317 + 8$
	21 10 57 p.m.	Birmingham ...	= 3rd mag.*	Orange.....	1 second	From $258^{\circ} - 7^{\circ}$ to $335 - 12$
	21 10 57 15 p.m.	Ibid	= 4th mag.*	Orange.....	0.5 second ...	From ϕ to θ Aquarii
	21 11 10 p.m.	Ibid	= 3rd mag.*	Blue	0.25 second...	$\alpha = \delta =$ From $77^{\circ} + 26^{\circ}$ to $84 + 24$
	21 11 13 p.m.	Ibid	= 4th mag.*	Reddish	0.75 second ...	Appeared at $87^{\circ} + 17^{\circ}$
	21 11 18 p.m.	Ibid	= Sirius	White	2 secs.; slow speed.	Appeared at σ Ceti
	21 11 44 p.m.	Ibid	> 1st mag.*	White	1 second	$\alpha = \delta =$ From $95^{\circ} + 20^{\circ}$ to κ Geminorum.
	22 12 44 a.m.	Radcliffe Obser- vatory, Oxford.	At first = 1st mag.*, then = γ .	Nucleus bright white, then green.	.....	Shot from α Pegasi past a group of stars in the con- stellation Pisces.
	22 10 32 p.m.	Ackworth, Pontefract (Yorkshire).	= 3rd mag.*	White	0.3 sec.; rapid speed.	$\alpha = \delta =$ From $12^{\circ} - 13^{\circ}$ to $2 - 17$
	22 10 33 p.m.	Ibid	= 3rd mag.*	White	0.5 sec.; very slow.	From $352^{\circ} - 7^{\circ}$ to $351.5 - 8$
	23 9 50 p.m.	Ibid	= γ	White	2 seconds.....	From $354^{\circ} + 22^{\circ}$ to $331 + 21$

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a bright streak for a second or two.	Length of a line from γ Cygni to β Lyrae.	Parallel to a line through γ Cygni and β Lyrae.		W. Jackson.
Five small meteors seen, leaving unusually persistent streaks.	$2\frac{1}{2}^{\circ}$ to 15° .	Radiant-point about 5° below, and 2° west of β Persei.	A bright auroral glare visible all over the north and north-eastern sky.	T. Crumplen.
	8°			J. E. Clark.
				
Left a red streak for 2 seconds.		From Radiant O		W. H. Wood.
Left a red streak		From Radiant O		Id.
		From Radiant R_3		Id.
	2°	Directed towards ν Orion; Radiant O.	Close to Radiant-point.	Id.
		Fell vertically, from Radiant $A_{11, 15}$.	View of the path intercepted 4° above the horizon.	Id.
		From Radiant O	From $10^h 45^m$ to $11^h 45^m$ p.m. six meteors seen. Night of the 22nd cloudy.	Id.
The nucleus was arrested for a moment in its flight and burst. It then advanced with increased brightness until it disappeared. It left a luminous cloud at the point of retardation for twenty seconds.			On the same night seventeen other meteors were observed.	B. Lucas; communicated by R. H. Alnatt, in the 'Sussex Mail.'
Left a slight train	12°			J. E. Clark.
				
At first scarcely visible, brightened gradually.	1°			Id.
				
Left a streak 1° in length	22°		Another meteor at $9^h 47^m$ p.m. moved at right angles to this one, near β Andromedæ.	Id.
				

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Nov. 2	h m 8 20 p.m.	Primrose Hill ...	= 3rd mag.* .....	.....	Very brief ...	From $358^{\circ} + 33^{\circ}$ to $355^{\circ} + 10$
	3 About 3 15 p.m.	Bilston, Staffordshire.	Large meteor	White and red .....	.....	In the S.E.
	3 About 3 15 p.m.	Leamington.....	As large as a rocket .....	.....	Moved slowly .....	.....
	3 About 3 15 p.m.	Rugby	Very large meteor	White, like ignited magnesium.	Very rapid motion.	Descended in the S.E., and disappeared on the verge of the horizon.
	3 About 3 15 p.m.	Birmingham ...	Appeared as large as the crescent moon.	.....	.....	Shot across the sky, and disappeared behind buildings in the E.S.E.
	3 About 3 15 p.m.	Ibid	Large and brilliant meteor.	White and red .....	.....	In the S.E. Fell apparently between the spectator and Yeardley church, i. e. nearly in the E.S.E.
	3 3 17 p.m.	Ibid	Shorter axis $\frac{1}{2}$; longer axis $\frac{3}{4}$ of the moon's apparent diameter.	Vivid white, and red.	3 seconds.....	Commenced at azimuth 33° E. of S., alt. 32° ; disappeared at azimuth 60° E. of S., alt. 10° or 12° . Positions measured from observed fixed landmarks.
	4 8 5 p.m.	Ibid	= 3rd mag.*	Pale blue ...	2 secs.; slow motion.	$\alpha = \delta =$ From $23^{\circ} + 9^{\circ}$ to $20^{\circ} + 14$

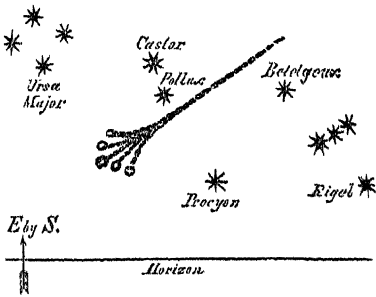
Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a train on its whole course which faded instantly.	20°	From Radiant N_{11} (?).....		T. Crumplen.
A white fireball with comet-like smoky tail following it. At Alcester it resembled a long streak of fire emitting much light and sparks in its course.			The sun shone, and the sky was almost cloudless. Seen also at Sarsden, Chipping Norton, and at Nottingham Hill, in London, as a large bright meteor in the south, going from west to east. An explosion was heard at the latter place.	'British Daily Post' and 'Times.'
In its course it appeared to have a zigzag form.		Descended towards the earth.	The meteor was also seen at Northampton, in full sunshine, emitting bright flames, and lasting a few seconds. 'The Times.']	'The Morning Star.'
		Rushing downwards ...	[Seen also at Hartlebury, as a shining silvery light descending in the south-east; and at Edmonton, moving from the south-west towards the east. Mr. Wood's M.S.]	'The Times.'
Meteor of a crescent form, like the moon a few days' old.			The wind was high, and clouds were passing quickly.	'Birmingham Daily Post.'
		Directed from the same quarter as the wind, or about W.S.W. to E.N.E., descending at an angle of 45° to the horizon.	The meteor appeared during a strong gale.	'Birmingham Daily Gazette.'
The crescent was bright white; the rest, near the tail, ruby-red; red flames issued from the rear, and merged into the tail for about 1°. The latter 15° in length, like smoke in sunshine, lasted only a moment. The meteor flickered in transit; diminished, and changed colour towards extinction, as if burnt out.			Notwithstanding the bright sunshine, the meteor was intensely luminous. Had it appeared at night, it would have equalled that of the 7th of October. A strong gale from W.S.W. blowing at the time, prevented any sound from being heard. See figure in Appendix II.	W. H. Wood.
				Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Nov. 6	h m s 7 35 p.m.	Primrose Hill, London.	= 2½ mag.* .....	.....	.....	$\alpha = \delta =$ From $310^{\circ} + 33^{\circ}$ to $293 + 23$; beginning at ϵ Cygni.
	8 6 27 p.m.	Ackworth, Pontefract (Yorkshire).	= 1st mag.*	Red	4 secs.; slow	From about $\alpha = \delta =$ $313^{\circ} - 20^{\circ}$ to about 275 - 30
	8 6 56 p.m.	Primrose Hill, London.	= 1½ mag.*	Bluish .....	.....	$\alpha = \delta =$ From $290^{\circ} + 37^{\circ}$ to $261 + 11$; ending near α Ophiuchi.
	8 8 18 p.m.	Ibid	= 3½ mag.*	Bluish .....	.....	$\alpha = \delta =$ From $315^{\circ} + 16^{\circ}$ to $293 + 12$; passing through Delphinus.
	8 10 51 p.m.	Ibid	= 2½ mag.*	White .....	.....	$\alpha = \delta =$ From $50^{\circ} + 23^{\circ}$ to $33 + 14.5$
	8 10 55 p.m.	Ibid	= 2nd mag.*	White	0.8 second	From $56^{\circ} + 26^{\circ}$ to $58 + 28$
	9 7 22 p.m.	Ackworth, Pontefract, (Yorkshire).	= 1st mag.*	Red	1 second	From about $78^{\circ} + 35^{\circ}$ to about 81 + 33
	13 10 16 p.m.	Primrose Hill, London.	= 1st mag.*	White .....	.....	From $55^{\circ} + 46^{\circ}$ to $91 + 29$
	14 2 33 a.m.	Madrid Observa- tory (Spain).	Large fireball .....	.....	Rather more than 1 sec.	First appeared be- tween λ and μ Ursæ Majoris.
	14 9 57 40 p.m.	Ackworth, Pontefract, (Yorkshire).	.....	Red	3 or 4 seconds	Passed from a little above ζ Tauri, through the Hy- ades, above α Ceti to 1° be- yond 20 Ceti (under Jupiter).

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a streak on its whole course which faded instantly.	17°			T. Crumplen.
Left no streak	40°		Oscillated in its flight...	J. E. Clark.
				
Left a very fine streak on its whole course which faded instantly.	Very long path.		A fine swift meteor ...	T. Crumplen.
Left a momentary streak..				Id.
Left a faint streak on its whole course.		This meteor and the next evidently radiated from Pleiades.		Id.
Left a bright train for half a second which faded gradually. Kite-shaped, thus— 	2½°	Upwards towards α Persci. A short path close to the Radiant-point.		Id.
Left no streak. Brightest in the middle of its course.	3°		On the night of the 13th clear for ten minutes, at 9 ^h 45 ^m p.m.; no meteors seen. The rest of the night overcast.	J. E. Clark.
Left a fine bright streak..				
		Downwards towards the left.	Sky clear about this time for 15 minutes. <i>No Leo meteors!</i>	T. Crumplen.
Left a bright luminous cloud which quickly expanded to a width of 6° or 8°, and faded in the centre so as to form a ring. It remained visible ten minutes.	4° or 5° ...	Towards α Ursæ Majoris		M. Aquilar.
No distinct nucleus. A shapeless mass 2° long and 10' broad.	Seen for about 80°.		Emerged at appearance from behind a house.	J. E. Clark.
				

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Nov. 14	h m s 1 12 a.m. (New York time).	Newhaven, U. S. America.	Large meteor	[Nucleus white; train greenish blue:—at Pallisades, T. P. Gillman.]	[0.5 second; at Pallisades.]	Centre of the persistent luminous streak 2° to the right of Jupiter.
14	5 6 45 a.m. (Newhaven time).	Ibid	Large meteor			Passed 1° S. of β Geminorum.
15	12 20 a.m. (local time).	Madrid Observatory (Spain).	Large meteor			Between β and ψ Ursæ Majoris.
15	1 30 a.m. (local time).	Bahia, Brazils, S. America.	Large meteor		A few seconds	Passed a little N. of the equator, from E.S.E. to W.N.W.
15	6 22 p.m.	Ackworth, Pontefract (Yorkshire).	=2nd mag.*	White	4 seconds.....	$\alpha = \delta =$ From $297^{\circ} - 13^{\circ}$ to $314 - 9$
15	6 51 p.m.	Ibid	=1st mag.*	Yellow	0.5 second ...	From $55^{\circ} + 23^{\circ}$ to $64 + 22$

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a nearly vertical streak 5° or 8° in length which became crooked, the upper part towards the right, and the lower part towards the left, thus— 2 It finally became horizontal, and was still faintly visible when the clock struck two.	[50° or 60° ; at Pallsades.]	Apparently conformable to the Radiant-point in Leo.	The meteor itself was not seen. Also observed at Poughkeepsie, Pallsades, Washington, &c. See Appendix I.	H. A. Newton; American Journal of Science, for May, 1869.
The central part of the train was visible six minutes, and moved towards a little east of north, 5° in three minutes.	.....	.....	For the height of this, and other meteor streaks observed in the United States on the same date, see Appendix I.	Id.
The nucleus was not seen; but it left a cloud of cometic light of varying shape, three or four times the apparent diameter of the moon.	.....	.....	Before a telescope could be directed to it, it disappeared. Probably the streak of a meteor as large as that which appeared at $2^h 33^m$ a.m. on the preceding morning. Until 4^h a.m., when the sky became overcast, the number of meteors observed was very small.	M. Aquilar; 'Les Mondes' for Dec. 3rd.
Burst. Left a well-defined streak which remained unchanged for five minutes; then gradually faded, and rolled itself from W. to E. into a luminous cloud, brighter than the Milky Way, which gradually disappeared, without moving, in fifteen minutes.	.....	.....	The night was clear and calm, with a slight breeze from the east. Several other meteors were seen on the same night, 24 hours later than the predicted time of their occurrence.	'Glasgow Daily Herald.'
.....	19°	 	Curved path, thus— 	A. K. Brown.
Left a momentary train 3° in length.	11°	Directed from Pleiades	.....	S. Thomson.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Nov. 15	h m s 8 40 p.m.	Ackworth, Pontefract (Yorkshire).	= 2nd mag.*	White	0·3 second ...	$\alpha = \delta =$ From $347^{\circ} + 11^{\circ}$ to $335 + 4$
15	9 0 p.m.	Primrose Hill, London.	= 3rd mag.*	Bluish	Moved swiftly	From $72^{\circ} \cdot 5 + 50^{\circ}$ to $55 + 23$
Dec. 5	About 10 30 p.m.	Manchester	= 3rd mag.*	Dull white ...	A rapid flash...	From ζ Geminorum to the hind paws of Ursa Major.
5	10 45 p.m.	Wilmslow (twelve miles S.S.E. from Manchester).	Large meteor	Blue	About 4 secs...	Plan of the me- teor's course a- mong the stars.
						
10	9 32 p.m.	Ackworth, Pontefract (Yorkshire).	= ♀	White	2 seconds.....	From about $\alpha = \delta =$ $57^{\circ} + 13^{\circ}$ to $41 + 3$
10	10 8 30 p.m.	Ibid	= 2nd mag.*	White	0·1 second ...	From $40^{\circ} + 8^{\circ}$ to $40 + 7$
10	10 19 p.m.	Ibid	= 2nd mag.*	White	1 second	From $71^{\circ} + 17^{\circ}$ to $66 + 13$
10	10 30 p.m.	Ibid	= 2nd mag.*	White	1·5 second ...	From $55^{\circ} + 7^{\circ}$ to $45 - 2$
10	10 44 30 p.m.	Ibid	= 1st mag.*	White	1 second	From $71^{\circ} + 14^{\circ}$ to $67 + 10$

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
	16°			J. E. Clark.
Left a faint streak		To right; almost horizontal.	A very fine blue meteor was seen on the 23rd.	T. Crumplen.
	15°			R. P. Greg.
Like the largest kind of sky-rockets. Left a fine line of fire, and burst into five or six splendid blue fire-balls like Roman-candles. (See the sketch of its apparent course.)	20° or 25°	From about S.W. to N.E. Inclining slightly downwards.	A magnificent object ...	G. H. Greg.
Disappeared suddenly; left no streak.	22°	Directed from Aldebaran	A brilliant meteor. Path not quite straight.	J. E. Clark.
	1°		Evidently not from the same Radiant-point as the last meteor.	Id.
	6½°		From the same direction as the meteor at 9h 32m p.m.	Id.
	14°		From the same direction as the last meteor.	Id.
	5½°		Almost parallel in direction to the meteor recorded before the last.	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. Dec. 10	h m s 10 51 30 p.m.	Ackworth, Pontefract (Yorkshire).	=3rd mag.*	White	1 second	$\alpha = \delta =$ From $83^{\circ} + 16^{\circ}$ to $77 + 13$
10	10 57 p.m.	Primrose Hill, London.	= 4.....	White	Moved slowly	From $165^{\circ} + 60^{\circ}$ to $165 + 40$
10	10 58 p.m.	Ackworth, Pontefract (Yorkshire).	= 4.....	White	2 seconds.....	From $69^{\circ} + 7^{\circ}$ to $50 - 1$
11	6 5 p.m.	Primrose Hill, London.	=3rd mag.*		Swift	From $81^{\circ} + 45^{\circ}$ to $95 + 70$
12	12 7 a.m.	Birmingham ...	=2nd mag.*	Blue	0.5 second ...	From θ to π_1 Canis Majoris.
12	12 15 a.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	From ν Androme- dæ to μ Pegasi.
12	12 15 15 a.m.	Ibid	=2nd mag.*	Blue	0.5 second ...	$\alpha = \delta =$ From $6^{\circ} + 15^{\circ}$ to $2 + 9$
12	12 18 a.m.	Ibid	= 4.....	White	2.5 seconds ...	From $20^{\circ} + 13^{\circ}$ to $2 0$
12	12 22 a.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	From $\frac{1}{2}$ (α Andro- medæ, γ Pegasi) to α Pegasi.
12	12 25 a.m.	Ibid	=1st mag.*	White	0.5 second ...	$\alpha = \delta =$ From $78^{\circ} + 36^{\circ}$ to $62 + 35$
12	Between 12 30 and 1 0 a.m.	Manchester	=3rd mag.*			From β Canis Mi- noris to the cluster of stars in Cancer.
12	Between 12 30 and 1 0 a.m.	Ibid	=3rd mag.*			From nearly Orionis, halfway to γ Eri- dani.
12	Between 12 30 and 1 0 a.m.	Ibid	=3rd mag.*		A rapid flash..	From η Aurigæ to δ Persei.
12	12 32 a.m.	Birmingham ...	=3rd mag.*	Blue	0.5 second ...	From π Androme- dæ to η Pegasi.
12	12 34 a.m.	Ibid	=1st mag.*	Deep red	3 secs. ; slow	From $\frac{1}{2}$ (α, δ) Ceti to ζ Eridani.
12	12 43 a.m.	Ibid	=2nd mag.*	Blue	0.5 second ...	Commenced at δ Canis Minoris.
12	12 46 a.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	From λ Orionis to γ Eridani.
12	12 47 a.m.	Ibid	> Sirius	White and red	2.5 seconds ...	From η to δ Pi- scium, and 6° beyond.
12	12 52 a.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	$\alpha = \delta =$ From $99^{\circ} - 10^{\circ}$ to Sirius.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
.....	7°.....		.....	J. E. Clark.
A large nucleus; faded slowly. ....	.....	Radiant doubtful; pro- bably from near Po- laris.	Path probably as stated. End only well ob- served.	T. Crumplen.
.....	21½°.....		.....	J. E. Clark.
Left a long thin train which faded instantly.	15°.....	Directed from α Au- rige.	.....	T. Crumplen.
Left no streak .....	.....	From Radiant G	A few meteors were seen on the night of the 10th.	W. H. Wood.
.....	.....	From Radiant G	On the night of the 11th the sky was overcast until 11 ^h 30 ^m p.m.; afterwards clear.	Id.
.....	.....	From Radiant G α .....	.....	Id.
Left a faint streak .....	.....	From Radiant G .....	.....	Id.
Left no streak.....	.....	From Radiant R _γ.....	.....	Id.
.....	.....	From Radiant G .....	.....	Id.
.....	.....	From Radiant V (?).....	.....	R. P. Greg.
.....	10°	From Radiant G .....	.....	Id.
.....	.....	From Radiant G .....	.....	Id.
Left no streak.....	.....	From Radiant G .....	.....	W. H. Wood.
Left a streak .....	.....	From Radiant T, near γ Ceti.	Path curvilinear	Id.
.....	6°	Towards α Hydre	From Radiant R G	Id.
.....	.....	From Radiant L G.....	.....	Id.
Nucleus white, with a red crescent. Left a faint streak (?).	.....	From Radiant R _γ , or γ.....	.....	Id.
.....	.....	From Radiant G .....	.....	Id.

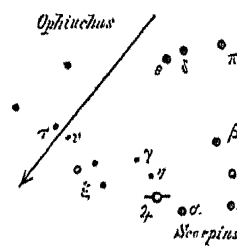
Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1868. h m Dec. 12 12 53 a.m.		Birmingham ...	=2nd mag.*	White	0.5 second ...	$\alpha = \delta =$ From $99^{\circ} + 10^{\circ}$ to $99 + 3$ From $275^{\circ} + 55^{\circ}$ to $272 + 49$
12 1 2 a.m.		Ibid	=1st mag.*	White	0.75 second ..	
12 1 4 a.m.		Ibid	=2nd mag.*	White	0.75 second ...	From $185^{\circ} + 76^{\circ}$ to δ Draconis.
12 1 34 a.m.		Ibid	=1st mag.*	White	0.5 second ...	From η to β Leporis.
12 11 56 p.m.		Manchester	=2nd mag.* .....	.....	A rapid flash..	Passed through the Pleiades.
13 12 21 a.m.		Ibid	=3rd mag.* .....	.....	.....	Passed through the Pleiades.
13 12 28 a.m.		Ibid	=2nd mag.*	Rose colour ...	0.4 second ...	From ζ to α Tauri..
16 6 4 p.m.		Primrose Hill, London.	= $3\frac{1}{2}$ mag.* .....	.....	.....	$\alpha = \delta =$ From $199^{\circ} + 11^{\circ}$ to $198 + 32$
24 3 33 a.m.		Glasgow	=2nd mag.*	White	0.8 second ..	Commenced at η Tauri.
1869. Jan. 1		Sweden	Large meteor .....	.....	.....	.....
10 7 35 p.m.		Aberdeen, Scotland.	Half the apparent diameter of the moon.	Reddish tinge	About 1 sec...	Passed close to Jupiter.
Mar. 27 9 55 p.m. (Paristime).		Paris	One-sixth of the apparent diameter of the full moon.	Red, enveloped in a white atmosphere.	Not more than 4 or 5 secs.	First appeared between Capella and the constellation Gemini. Crossing the latter, and Cancer, and passing above Procyon, it disappeared near the head of Hydra.
Apr. 3 Between 4 0 and 5 0 a.m.		Carlisle .....	.....	.....	Travelled at a quick speed.	Passing over the city.
11 10 1 p.m. (Turintime)		Moncalieri, Turin, Piedmont.	Nearly as bright as Jupiter.	Greenish	Slow speed ...	From ϕ Leonis to δ Corvi.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
.....	.....	From Radiant G .....	.....	W. H. Wood.
.....	.....	From Radiant G <i>a</i>	Twenty meteors per hour were counted by one observer. Observations discontinued at 1 ^h 10 ^m a.m.	Id.
.....	.....	From Radiant G	On the nights of the 12th and 13th the sky was overcast.	Id.
.....	.....	From Radiant L <i>g</i> .....	.....	Id.
.....	12°	Directed from β Tauri...	From Radiant G	R. P. Greg.
.....	3°	Directed from β Tauri...	From Radiant G	Id.
.....	.....	From Radiant G	A bright meteor	Id.
Left a streak which faded instantly.	10°	Directed from near Polaris.	.....	T. Crumplen.
Increased gradually in brightness; drew a short tail of sparks after it. Left no streak.	1°	Directed from δ Persæ	Clear sky; no moon. No other meteor seen in twenty minutes.	A. S. Herschel.
Stonefall at Lake Malar, in the Upland.	.....	.....	.....	'Association Scientifique de France,' No. 105.
The meteor burst, and terminated in what appeared to be three globes of light, each about one-third the apparent diameter of the full moon.	10° or 15°.	From N.N.E. to S.S.W.	A very brilliant fireball	'Glasgow Evening Citizen,' Jan. 12th.
At first as bright as Mars, it increased to one-sixth of the apparent diameter of the full moon, which was near its path; numerous sparks, issuing from it, produced a luminous appendage; and it shone brightly through clouds, which dimmed the stars	Not less than 40°.	From N.W. to S.E. ...	A large and brilliant meteor. First appeared at $\alpha = \delta = 98^\circ + 36^\circ$ crossed the ecliptic at $114 + 21$ disappeared at 126 0	M. Laussedat; 'Comptes Rendus' for Mar. 29th, 1869; vol. lxxviii. p. 784.
Resembled a sheaf of fire, with connected streamers of light, which at last burst and cast a great light around.	.....	From E. to W.....	Cast a lurid glare on the landscape, and lit up the heavens with a singular brightness. [The meteor was seen at the same hour at Manchester.]	'Glasgow Daily Herald,' April 5th.
.....	.....	Course not quite straight; undulating.	.....	Francesco Denza; 'Bulletins de l'Académie de Belgique,' vol. xxvii. p. 633.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. Apr. 11	h m 10 1 p.m. (Turintime)	Bergamo, Italy..	Bright meteor.....	.....	.....	From Regulus to a point between ν and κ Hydra, at $\alpha = \delta = 144^{\circ}5' - 13^{\circ}$
11	10 35 p.m. (Turintime)	Moncalicri, Turin, Piedmont.	Appeared about as large as Jupiter.	Red and green	Slow speed ...	From near η Ursa Majoris to near χ Boötis.
11	About 10 34 p.m. (Turintime)	Bergamo, Italy..	Bright meteor .....	.....	.....	First appeared between γ and ζ Leonis. Disappeared at a point in Cancer, at $\alpha = \delta = 136^{\circ} + 17^{\circ}$
May 5	About 11 30 p.m. (Turintime)	Moncalicri, Turin, Piedmont.	$= 4$	Reddish	Moderate speed.	From near Spica Virginis to near γ Hydra. Disappeared very near the horizon.
15	3 20 p.m.	Oxford	Large meteor	Pale red; sparks purple.	About 12 secs.	Disappeared shortly before it reached the horizon.
22	About 9 45 p.m. (Paris time)	Yannes, France...	Large meteor .....	.....	.....	Left a long streak. Stonefall at Cléguérec.
29	11 20 p.m.	Regent's Park, London.	Very large meteor..	Like the electric light.	Slow and stately motion.	From between η Ursa Majoris and α Corone, it passed 10° or 12° to the left of Saturn, below which point it burst.
29	11 22 p.m.	Hurstgreen (Sussex).	As bright as Mars or Jupiter.	Orange-red ...	Slow speed ...	From altitude about 20° in the south-west to about 5° above the horizon, one point more towards the south.

Appearance ; Train, if any, and its Duration.	Length of Path.	Direction ; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
			Possibly identical with the last.	M. Zezioli ; 'Bulletins de l'Académie de Belgique,' vol. xxvii. p. 633.
Burst, with sparks. Left a very bright persistent streak.			Two other bright meteors on this evening cast such a strong reflected light as to attract the attention of observers who were looking in the opposite direction.	Francesco Denza (Ibid.).
			Possibly identical with the last.	M. Zezioli (Ibid.)
Followed by a tail of sparks. At a point about two-thirds along its course ($\alpha = 197^\circ$ $\delta = -14^\circ$), it appeared to descend below, and be visible through a dark cloud.			Rocket-like. Appeared suddenly.	Francesco Denza; Ibid. p. 632.
Like a large shooting-star. It burst into what seemed to be myriads of purple sparks, which gradually vanished.		From W. to E.		'The Standard,' May 16th.
Nucleus kite-shaped. Burst like a rocket, the fragments burning out gradually.	More than 30°.		Stones fell at Clégnerre, Vendée, south of France. [Seen also at l'Orient, by Mons. Bourdillon.]	M. Arrondeau ; 'Association Scientifique de France,' No. 123.
			Intensely luminous, lighting up the heavens. Commencement of the meteor's course not seen.	Communicated by T. Crumplen.
Disappeared gradually. No sparks or streak.	15°	Descending obliquely towards the left.	The sky in that direction was quite clear.	Communicated by A. S. Herschel.



Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. May 31	h m 10 52 p.m.	Christ College, Cambridge.	Large meteor	Deep yellow, then orange, then light blue.	2 or 3 seconds	From $\frac{1}{2}$ (λ , σ) to $\frac{1}{2}$ (ν , τ) Ophi- uchi, and 8° further. Disap- peared behind houses.
						
31	About 11 0 p.m.	Battle (Sussex).	Larger than any of the planets.	Bright flame- colour.	.....	.....
31	About 11 0 p.m.	Hurstgreen (Sussex).	Appeared nearly as large as the full moon.	Yellowish ...	Moderate speed.	From some height above the S.S.E. horizon to very near the east ho- rizon.
31	About 11 0 p.m.	Horsemonden, Brenchley (Kent).	Large fireball	Yellow, red, and purple.	About 8 secs., slow speed.	First seen at alti- tude 35° or 40° in the E.S.E. Disappeared be- hind trees 3° or 4° above the E.N.E. horizon.
31	About 11 0 p.m.	Wrotham, Maid- stone (Kent).	As large as the full moon.	.....	Proceeded slowly.	.....

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
The shape of the meteor was rounded in front, throwing off flakes of flame behind.	About 30°	Directed nearly from α Serpentis.	The view of the last part of the meteor was intercepted by houses.	A. T. Atchison.
Rocket-like. Nucleus as bright as the Diamond light, brightly defined in front, drawing behind to a short tail with sparks. Disappeared gradually. Left no streak.	.....	.....	The light cast was sufficient to have picked up a pin. A clear night.	J. Harmer; communicated by A. S. Herschel.
A round ball, which gradually disappeared without leaving any streak or sparks.	About 50°	From W. to E.	About four minutes and a half after its disappearance a report was heard as of a distant explosion.	Communicated by A. S. Herschel.
Like a mass of fire: pear-shaped.	45°	From W.S.W. to E.N.E.	Positions carefully observed by landmarks. Five minutes after the disappearance a report was heard which shook the earth and made the windows rattle. [The flash of light and the report were perceived within doors at Horsemonden, and at Hawkhurst, with an interval of four or five minutes between them. Both the flash and the report were double.—A.S.H.]	II. Marriot; communicated by A. S. Herschel.
.....	.....	From S.W. to N.E.....	Shortly after its disappearance three reports were heard as of distant cannons. The houses shook at Meopham. Seen generally around Wrotham.	W. E. Hickson.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. May 31	h m 11 2 p.m.	Llandudno, N. Wales.	Large meteor	Intense green. Tail red with red sparks.	.....	Passed a little below Arcturus. Disappeared behind Little Orme's Head (nearly due east).
31	11 4 p.m.	Torquay (Devonshire).	Appeared as large as the full moon.	Bright red, with red tail. Reflected light green.	.....	First appeared about 30° above the horizon, a little south of east, and disappeared below the east horizon.
31	11 4 p.m.	London	Very large meteor..	Yellowish ...	Moving with great velocity.	First appeared 30° above the horizon.
31	11 5 p.m.	Ibid	Large fireball .....	.....	.....	Appeared over the houses, moving eastwards.
31	11 5 p.m.	Rickmansworth..	Large meteor; half as bright as the moon.	White, like the magnesium light. Tail red.	About 1 sec.; motion not very rapid.	Disappeared about 6° or 8° above the horizon.
31	About 11 5 p.m.	Ormskirk (Lancashire).	Large fireball	Blue, red, and yellow.	.....	Disappeared at the horizon.
31	11 14 p.m. (Paris time)	Paris	Half the apparent diameter of the full moon.	White, then red.	5 or 6 seconds	Commenced in Camelopardus, 6° or 8° west of due north, at the same altitude as the three lowest stars of Cassiopeia, and crossed the constellation Perseus towards Taurus. Disappeared before reaching the horizon.
31	About 11 15 p.m. (Paris time)	Place du Carusel, Paris.	Large fireball .....	.....	.....	In the direction of the Buttes Montmartre.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
A large luminous body, drawing behind it a streak of red light 5° or 6° in length, from which red fire seemed to drop.			Immediately after its passage two bright flashes of light followed which illumined the whole sky. Seen by many persons on the Parade.	Communicated by J. B. Dancer.
The bright red body left behind it a tail of considerable length, and of the same colour as the head. All the sky and the landscape was lighted up with a pale green light.		From W. to E.	It did not describe a perfect arc, but about halfway through its course it made a sudden rise, when the light flashed out with far greater brilliancy; after that it again tended downwards.	H. T. Mackenzie.
When within 20° of the horizon it broke up.		From due W. to E.	No sound of an explosion was heard. [Seen also from the bridge in St. James's Park, descending apparently into the water; like a firework at the Crystal Palace. —A. S. H.]	L.; 'The Times,' June 3rd.
Brilliant ball of fire and train of sparks like a comet. Burst into several balls, like those of Roman candles.			Cast shadows as bright as those of sunlight.	'Morning Herald,' June 3rd.
Shaped like a Tadpole. The body elongated and well defined. The tail, which was fiery-red, shook, as if violently contorted.		From W. to E.; parallel to the horizon.	The night was bright with starlight; and the meteor appeared to fall in a neighbouring field.	T. J. Buckton.
Like a ball of blazing tow, emitting flames of blue, red, and yellow light.		Fell obliquely downwards, from right to left.	.....	W. Newsam.
At its first appearance it increased, almost stationary, to half the apparent width, and at least the full brightness of the moon. As it advanced, it drew behind it a white tail, and changed its colour to bright red.			The houses and all surrounding objects were brilliantly illumined by its light.	Mons. Robinet; 'Association Scientifique de France,' Nos. 124 and 126.
A bolide, drawing a long fiery tail, and scattering sparks on its course.		Fell vertically downwards.	The same meteor was also seen at Ilavres.	'Le Temps,' June 2nd.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. May 31	h m About 11 15 p.m. (Brussels time).	Brussels	Half the apparent diameter of the full moon.	Nucleus yel- lowish white. Tail red and green.	.....	Appeared in the W.S.W., at alti- tude about 45°, and disappeared behind trees, due west, at altitude about 35°.
31	About 11 15 p.m.	Ightham (Sussex).	Large and brilliant meteor.	.....	.....	Appeared in an easterly direc- tion.
June 5	8 55 p.m.	Greenwich Park.	Brighter than Ju- piter.	White	About 1 sec..	From near the zenith to near Arcturus.
6	1 29 a.m.	London	=3rd mag.*	White	0.5 second ...	Commenced at θ Draconis.
10	11 0 p.m.	Hawkhurst (Kent).	=1st mag.*	White	0.3 sec.; very swift.	From τ , Serpentis, two-thirds of the way to z Virginis.
July 2	Morning ...	Littlehampton (Sussex).	Large meteor .....	.....	.....	At an altitude of 45°.
7	10 55 p.m.	Hawkhurst (Kent).	=1st mag.*	White	1 second	From ϵ to 2° fol- lowing α Boötis.
9	11 0 p.m.	Ibid	=1st mag.*	Yellow	1 second	Commenced at λ Aquila.
10	10 56 p.m.	Ibid	=3rd mag.*	Yellow	0.8 second ...	From χ Herculis to η Ursæ Majoris.
10	11 7 p.m.	Ibid	= α Lyrae	White	1.4 second ...	Commenced at θ Serpentis.
10	11 22 p.m.	Ibid	=3rd mag.*	Yellow	0.8 second ...	From Λ Draconis to z Ursæ Mi- noris.
10	11 26 p.m.	Ibid	=2nd mag.*	White	0.5 second ...	Centre of path at $\frac{1}{2}$ (z , η) Herculis.
11	10 44 p.m.	Ibid	=2nd mag.*	White	0.7 second ...	From $\frac{1}{2}$ to $\frac{3}{4}$ of the way from θ Cas- siopeie to ι Ta- randi.
11	10 49 p.m.	Ibid	=1st mag.*	Yellow	0.5 second ...	Commenced at p Boötis.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Elongated nucleus, drawing a tail of sparks, which was at first red, and afterwards of a greenish tinge.	.....	.....	The glare which it cast was so bright that a person standing at a window, facing towards the north, thought that it lightened. Seen also at Verviers, Tournay, Stavelot, &c.	'Bulletins de l'Académie de Belgique' for June 1869, vol. xxvii. p. 631.
.....	.....	From W. to E.	Some who saw the meteor heard a loud report follow its appearance.	'Sussex Express,' June 4th.
Left no streak or sparks...	About 15° .....	.....	In twilight. Arcturus the only star visible in the sky, which was quite clear.	Communicated by A. S. Herschel.
Left no streak.....	1°	Directed towards ζ Ursæ Minoris.	No other meteor in an hour, in a fifth part of the sky. Clear; no moon. Dawn beginning to appear.	A. S. Herschel.
Left no streak.....	.....	Curved path, thus— 	Turned in the middle of its path towards Ophiuchus. No other meteor seen in thirty minutes. Sky half clear; no moon.	Id.
Burst with the appearance of a rocket.	.....	Passed from S. to N.	A very brilliant meteor.	'Sussex Express,' July 6th.
Brightest at the middle of its course. Left no streak.	.....	.....	No other meteor seen in forty-five minutes. Sky hazy; no moon; one observer.	A. S. Herschel.
Brightest at the middle of its path. Left no streak.	8°	Directed from θ Serpentis.	No other meteor seen in forty-five minutes. Sky hazy; no moon.	Id.
Left no streak .....	.....	.....	.....	Id.
Left a streak at the middle and brightest part of its course for half a second.	30°	Down the division of the Milky Way.	.....	Id.
Left no streak.....	.....	.....	.....	Id.
Brightest at middle of its course. Left no streak.	4°	Directed from ε Herculis.	Four meteors seen in forty-five minutes. Very clear sky; no moon.	Id.
Left a streak at the middle and brightest part of its course for half a second.	.....	.....	.....	Id.
Brightest at middle of its course. Left no streak.	4°	Directed from ζ Bootis	.....	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. July 11	h m s 11 5 p.m.	Hawkhurst (Kent).	=2nd mag.*	White	1.2 second ...	From γ Lyrae to ϵ Herculis, and 6° further.
	11 11 10 p.m.	Ibid	=2nd mag.*	Yellow	0.5 second ...	Commenced at L Camelopardi.
	11 11 15 p.m.	Ibid	=3rd mag.*	Yellow	0.6 second ...	From θ Draconis to $\frac{1}{2}$ (ν , τ) Urse Minoris.
	11 11 17 p.m.	Ibid	=3rd mag.*	Yellow	0.7 second ...	From A Draconis to $\frac{1}{2}$ (ξ , β) Urse Minoris, and 4° further.
	14 11 7 p.m.	Ibid	=3rd mag.*	Yellow	0.6 second ...	From $\frac{1}{2}$ (ϵ , γ) to β Cygni.
	15 10 42 p.m.	Ibid	=2nd mag.*	White	0.5 second ...	From $\frac{1}{2}$ (α , π) to η Draconis.
	15 10 42 30 p.m.	Ibid	=1st mag.*	White	0.5 second ...	From ϵ to $\frac{1}{2}$ (η , II) Draconis.
	15 10 56 p.m.	Ibid	=Sirius, then=1st mag.*.	White, then orange-yellow.	3.5 seconds ...	From $\frac{1}{2}$ (β Aquilæ, ϵ Delphini) to 2° following χ Cephei.
	15 11 20 p.m.	Ibid	=1st mag.*	White	0.5 second ...	From ξ to ν Cygni.
	15 11 20 30 p.m.	Ibid	=1st mag.*	White	0.6 second ...	From ι Draconis to θ Bootis.
	15 11 32 p.m.	Ibid	=3rd mag.*	Yellow	0.2 second ...	From g to A Draconis.
	16 About 9 30 p.m.	Ibid	Large meteor	White	About 2 secs...	Disappeared about 10° above the horizon, due S.
	16 11 35 p.m.	Ibid	> $\frac{1}{2}$	White	0.8 sec. while in sight. Total duration 2.5 secs.	From 4° above γ Delphini to 2° west of ϵ Pegasi.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left a streak for 1 second				A. S. Herschel.
Left no streak	6° while in sight.	Fell vertically. Directed from $\frac{1}{2}$ (ω , γ) Cephei.	A side view, only, of the meteor was seen.	Id.
Left no streak				Id.
Left no streak			Six meteors seen in forty - five minutes. Very clear sky; no moon; one observer.	Id.
Left no streak			No other meteor seen in forty - five minutes. Clear sky; no moon.	Id.
Brightest at the middle of its course. Left no streak.			Two very similar meteors following each other, almost immediately, in the same part of the sky.	Id.
Brightest at the middle of its course. Left no streak.				Id.
In the first half of its course a bright white meteor equal to Sirius, leaving a slight streak; then collapsed to a yellow first-magnitude star, drawing a short tail of red sparks; it disappeared suddenly.	45°	Almost vertically upwards to the zenith.	A very striking meteor	Id.
Brightest at the middle of its course. Left no streak.			This meteor and the next followed each other in quick succession.	Id.
Brightest at the middle of its course. Left no streak.				Id.
Left no streak				Id.
No sparks or streak; disappeared gradually.	15° or 20°	Nearly horizontal	In twilight. Very bright meteor; seen by several persons.	Communicated by A. S. Herschel.
				
Globular nucleus, with very quickly intermittent light. Disappeared suddenly. No streak or sparks.	8° or 10° while in sight.	Directed from near η Cygni. Radiant B ₂ in head of Draco.	Two rapid white flashes in one second drew the observer's attention to the meteor. The final part, only, of the meteor's course was seen, in a clear space between clouds.	A. S. Herschel.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. July 16	h m 11 35 p.m.	Kensington, London.	Splendid meteor....	Light of intense white-heat.	Immensely rapid.	Shot from the zenith towards the S.S.E.
16	11 35 p.m.	In the north of London.	Large meteor	Nucleus quite white.	Rapid motion.....	
16	11 36 p.m.	Beckenham (Kent).	.....	Reddish-yellow.	1 or 2 seconds	Disappeared about 45° to the right of ϵ Pegasi.
17	10 34 p.m.	Hawkhurst (Kent).	= 2nd mag.*	Yellow	0.6 second ...	Disappeared at γ Draconis.
20	9 35 p.m. (local time).	New York, United States.	Half the apparent diameter of the moon.	Emerald-green.	5 seconds.....	First appeared about 45° above the N.E. horizon, at a point $10'$ north of α Cygni, and disappeared in a N. by W. direction.
21	11 40 p.m.	Ibid	= 2nd mag.*	Yellow	0.6 second ...	Disappeared at ϵ Tarandi.
Aug. 3	9 10 p.m. (Geneva time).	Brieg, Vallais, Switzerland.	= 1st mag.*.....	White	1.5 sec.; slow motion.	From ζ Cassiopeie to γ Persei.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
It began in a thin streak of red sparks, and rapidly increased to its greatest splendour; of an intense white heat, giving off jets or sputterings of light, on its whole course, from both sides of its body. Its disappearance was extremely sudden, as if its substance were wholly consumed. For a second there was left a train of sparks.	The whole course of the meteor was extremely short.	From N.N.W. to S.S.E.	The sky was very clear, and the meteor was well seen from first to last. No sound of a report was heard.	The Duke of Argyll; 'The Times,' July 21st.
The meteor's path was not continuously illuminated, but appeared broken, for quite half the length of its flight, into a train of brilliant sparks. It terminated in an explosion of vivid incandescence, dividing the principal mass into smaller bodies, which were very quickly extinguished.	.....	.....	The atmosphere was quite clear and calm. No sound of a report was heard after its extinction.	John Spiller; 'The Times,' July 21st.
By a glance at the meteor, at the instant of its disappearance, it was of this form:— 	Very brief course while in sight.	The prolongation of the brief stage of its apparition which was visible was directed, apparently, from Aquila.	Two flashes in quick succession, with half a second between them, like faint lightning reflected upon surrounding objects, drew the observer's attention to the meteor. No sound was heard.	F. Howlett.
Left no streak	8°	Directed from ϵ Lyrae	.....	A. S. Herschel.
The nucleus was followed by a train of red, yellow, and blue light. Disappeared without bursting.	30°	.....	The meteor cast a strong shadow, even during moonlight.	Communicated by R. P. Greg.
Brightest at the middle of its course. Left no streak.	10°	Directed from σ Cephei	Sky quite clear. No other meteor in fifty minutes seen in $\frac{1}{4}$ of the sky. Full moon; one observer.	A. S. Herschel.
Stellar nucleus. No train or sparks.	.....	After midnight meteors frequent (one in two or three minutes in half the sky). Radiant Cassiopeia, Perseus, and Auriga.	Another meteor appeared very shortly afterwards in Andromeda. Very clear sky.	Id.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. Aug. 4	h m s Evening ...	Manchester ...	= 2nd or 3rd mag.*	.....	.....	.....
8	8 45 p.m.	Rigi, Lucerne, Switzerland.	= Sirius	White	1 second	From γ Honorum to π Pegasi.
9	10 37 p.m.	Birmingham ...	= 3rd mag.*	Pale blue.....	0.5 second ...	$\alpha = \delta =$ From $24^{\circ} 52'$ to α Trianguli.
9	10 38 p.m.	Ibid	= 1st mag.*	Pale yellow ...	0.75 second ...	From ϕ to π Cas- siopeia.
9	10 43 p.m.	Ibid	= 2nd mag.*	White	0.5 second ...	$\alpha = \delta =$ From $18^{\circ} + 42'$ to $17 + 27$
9	10 48 p.m.	Ibid	> 1st mag.*	Brilliant blue..	0.5 second ...	From ϕ to μ An- dromeda.
9	10 55 p.m.	Ibid	= 2nd mag.*	White	0.75 second ...	From α Pegasi to α Aquarii.
9	10 59 p.m.	Hawkhurst (Kent).	> 1st mag.*	Yellowish- green.	.....	Passed between α and β Androme- da; near the east horizon.
9	11 0 p.m.	Birmingham ...	> 1st mag.*	Pale blue.....	0.5 second ...	From α Lyrae to α Ophiuchi.
9	11 5 p.m.	Ibid	> 1st mag.*	Pale yellow ...	0.5 second ...	From $\frac{1}{2} (\alpha, \delta)$ Ursa Majoris, $\alpha = \delta =$ to $186^{\circ} + 50'$
9	11 12 p.m.	Ibid	= 1st mag.*	Blue	0.75 second ...	From γ to $\frac{1}{2} (\beta, \theta)$ Persei.
9	About 11 15 p.m.	Hawkhurst (Kent).	= 1st mag.*	Bluish .....	.....	Close to, and almost across α Andro- meda.
9	11 16 p.m.	Birmingham ...	= 3rd mag.*	Blue	1 second	From λ to μ Persei
9	11 19 p.m.	Ibid	= 3rd mag.*	Blue	1 sec.; slow speed.	From $\frac{1}{2} (\gamma, \lambda)$ to θ Aquarii.
9	About 11 20 p.m.	Hawkhurst (Kent).	> α Lyrae	Pale yellow ...	.....	From just below ν to ζ Pegasi.
9	11 24 p.m.	Birmingham ...	> 1st mag.*	Yellow	1 second	$\alpha = \delta =$ From $354^{\circ} + 3'$ to δ Aquarii.
9	About 11 25 p.m.	Hawkhurst (Kent).	= α Cygni .....	.....	Swift	Commenced at α Aquilae.
9	About 11 30 p.m.	Ibid	= α Lyrae	Yellow .....	.....	Passed near δ Ca- melopardi.
9	11 38 p.m.	Birmingham ...	= 3rd mag.*	Blue	0.5 second ...	Commenced at η Piscium.
9	11 39 p.m.	Ibid	= 2nd mag.*	Blue	1 sec.; slow motion.	$\alpha = \delta =$ From $23^{\circ} + 22'$ to $29 + 23$
9	About 50 11 48 p.m.	Hawkhurst (Kent).	> 1st mag.*	Greenish- white.	.....	From γ Honores to γ Pegasi.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Seven meteors seen in fifty minutes.		Two of them, only, were directed from Perseus.	Very clear sky; no moon; one observer.	R. P. Greg.
Left a streak for 1 second		Path curved, concave towards Lacerta.	No other meteor seen in twenty minutes, until 9 p.m. Sky one-fifth cloudy; no moon.	A. S. Herschel.
.....		Directed from ϵ Cassio- peia.	Clear sky.....	W. H. Wood.
Left a reddish streak		Directed from ϵ Cassio- peia.	.....	Id.
.....		Directed from ϵ Cassio- peia.	.....	Id.
Left a green streak.....		Directed from χ Persei..	.....	Id.
Left a streak 15° long ...		Directed from γ Persei..	.....	Id.
Left no streak			Seen through a massive cloud.	Communicated by A. S. Herschel.
.....		Directed from ϵ Cassio- peia.	.....	W. H. Wood.
Left a red streak		Directed from η Persei..	.....	Id.
Left a broad green streak.....		Directed from γ or κ Persei.	.....	Id.
Left no streak	2°	Directed towards Cas- siopeia.	.....	Communicated by A. S. Herschel.
Left a dense streak.....		Directed from η Persei..	.....	W. H. Wood.
Left a streak		From Radiant $T_{2, 3, 1}$ ..	.....	Id.
Left a train for $1\frac{1}{2}$ second.....			Disappeared behind a cloud. Exact obser- vation.	Communicated by A. S. Herschel.
Left a long streak		Directed from γ Persei..	.....	W. H. Wood.
Left no streak	10°	Directed from γ Cygni..	.....	Communicated by A. S. Herschel.
Grew rapidly brighter, and left a faint streak for $\frac{1}{2}$ a second.		Directed from γ , η Per- sei.	Seen through a slight cloud.	Id.
.....	3°	Directed from η Persei..	.....	W. H. Wood.
Left a streak		From Radiant T_1	Sixteen meteors counted in one hour by one observer.	Id.
Left a streak on its course as far as ϵ Pegasi for half a second.			Exact observation	Communicated by A. S. Herschel.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. h m s Aug. 9 11 55 p.m.		Hawkhurst (Kent).	> 1st mag.*		Asudden flash; $\frac{1}{2}$ second.	Near δ Camelopardi
10 12 3 a.m.		Ibid	Nearly = Capella ...	Whitish-green	Nearly 2 secs.	From γ to β Casiopeæ, and onwards as far as ϵ Lacertæ.
10 About 12 20 a.m.		Ibid	> 1st mag.*	Green		Commenced between β and η Cygni, and shot across Delphinus.
10 0 31 a.m.		Ibid	> 1st mag.*	Greenish	Nearly 1 sec.	Close to the left upper side of the Cluster at χ Persei.
10 9 57 p.m.		Birmingham ...	= 1st mag.*	Greenish		From θ Sagittæ to σ Aquilæ.
10 11 7 p.m.		Chalons, Sur Marne, France.	= 1st mag.*	White	1 second	From $\frac{1}{2}$ (F, K) Herculis to p Tauri Poniatovii.
10 11 12 p.m.		Ibid	= 3rd mag.*	Yellow	0.5 second ...	Disappeared at θ Serpentis.
11 10 27 p.m.		Birmingham ...	= 3rd mag.*	Blue	0.5 second ...	From $\frac{1}{2}$ (δ Ursæ Majoris, Cor Caroli), to Cor Caroli.
11 10 30 p.m.		Hawkhurst (Kent).	= 3rd mag.*	White	0.8 second ...	From β Herculis to ϵ Delphini.
11 10 31 p.m.		Ibid	= 1st mag.*	White	1 second	Crossed ϵ Psalterii
11 10 31 p.m.		Birmingham ...	= 2nd mag.*	Blue	0.5 second ...	From σ_1 to β Ursæ Majoris.
11 10 35 p.m.		Hawkhurst (Kent).	= 1st mag.*	Green	1 second	Passed ϵ and δ , towards ξ Draconis.
11 10 37 p.m.		Ibid	= 2nd mag.*	White	1.2 second ...	From μ Cygni to ϵ Delphini.
11 About 10 40 p.m.		Ibid	= 1st mag.*	Green	0.75 second ...	From $\frac{1}{2}$ (Polaris, γ Cephei) to ν Draconis, and some degrees further.
11 10 41 p.m.		Ibid	= 2nd mag.*	White	0.8 second ...	From γ to κ Cephei
11 10 44 p.m.		Ibid	= 3rd mag.*	Yellow	1 sec.; slow speed.	From ϵ Delphini, halfway to μ Cygni.
11 10 44 30 p.m.		Ibid ...	= 3rd mag.*	White	0.5 second ...	Commenced at ι Pegasi.
11 10 45 p.m.		Ibid	= 1st mag.*	White	0.8 second ...	From ϵ Herculis to α Ophiuchi.
11 About 10 45 p.m.		Ibid	> 2nd mag.*			From g Honorum to ϵ Pegasi.

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Grew gradually brighter...	Very short path.			Communicated by A. S. Herschel.
Left a fine train in the first part of its course, from γ to β Cassiopeia, for half a second.			Exact observation. Three more conformable meteors, very swift, in Aries, Delphinus, and Cygnus, were seen before 12 ^h 40 ^m a.m.	Id.
Left no streak.....	10° or 12°..			Id.
Left a short but very dense and distinct streak of a greenish-blue colour for half a second.		Directed towards θ Cassiopeia.	A very well-defined and beautiful object.	Id.
Left a green streak for 2 seconds.		Directed from ϵ Cassiopeia.		W. H. Wood.
Left a streak for 1 second			About half of the sky overcast.	A. S. Herschel.
	8°.....	Directed from δ Vulpecula.	Five meteors seen in 30 minutes in $\frac{1}{3}$ th of the sky; generally clear; no moon.	Id.
		Directed from γ Persei.	A very fine night	W. H. Wood.
Left no streak.....				A. S. Herschel.
	8°.....	Directed from χ Piscium.		Id.
		Directed from α Persei.		W. H. Wood.
Left a streak for half a second.				Communicated by A. S. Herschel.
Left a streak for 1 second				A. S. Herschel.
Left a streak in the first part of its course.		Towards γ Draconis		Communicated by A. S. Herschel.
Left a streak for 1 second				A. S. Herschel.
Gradually faded out. Left no streak.			From a southern Radiant	Id.
	5°.....	Directed from β Cygni.		Id.
Left a streak for 2 seconds				Id.
Left no streak	12°			Communicated by A. S. Herschel.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude and Azimuth.
1869. Aug. 11	h m s About 10 45 p.m.	Hawkhurst (Kent).	=3rd mag.	White	0.7 second ...	From δ Cygni to γ Lyra.
	11 About 10 45 p.m.	Ibid	=2nd mag.* .....	.....	.....	From under β Andromedæ to under γ Pegasi.
	11 About 10 45 p.m.	Ibid	=2nd mag.*	White	0.7 second ...	From κ Cygni to θ Herculis.
	11 About 10 50 p.m.	Ibid .....	.....	.....	.....	Passed close to h Lacertæ.
	11 10 54 p.m.	Birmingham ..	=1st mag.*	White	0.5 second ...	Commenced at 2 Ursæ Majoris.
	11 About 10 55 p.m.	Ibid	=3rd mag.* .....	.....	.....	Centre at $\frac{1}{2}$ (α Cephei, c Lacertæ).
	11 10 56 p.m.	Hawkhurst (Kent).	=3rd mag.* .....	.....	.....	Shot across γ Cygni
	11 10 58 p.m.	Ibid	>2nd mag.* .....	.....	.....	From $\frac{1}{2}$ (α Andromedæ, β Pegasi) to β Trianguli.
	11 11 5 30 p.m.	Ibid	=2nd mag.* .....	.....	.....	Commenced at $\frac{1}{2}$ (α , β) Andromedæ.
	11 11 10 p.m.	Birmingham ..	=3rd mag.*	Dull	1 second	From $\frac{1}{2}$ (γ , ϕ) to γ Andromedæ.
	11 11 17 p.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	Commenced at γ Pegasi.
	11 11 17 30 p.m.	Hawkhurst (Kent).	=1st mag.* .....	.....	Slow speed ...	Centre at K Herculis.
	11 11 26 p.m.	Ibid	=Sirius	Green	Fully 1 second	From α Cephei to between γ and e Cygni, disappearing close to i Cygni.
	11 11 30 p.m.	Birmingham ..	> 1st mag.*	Green	0.5 second ...	$\alpha = 307^\circ + 19^\circ$ to $291^\circ + 13^\circ$
	11 11 30 p.m.	Ibid	> 1st mag.*	Green	0.75 second ...	From β Cygni to $\alpha = 278^\circ + 12^\circ$ Passed near γ Trianguli.
	11 11 31 p.m.	Hawkhurst (Kent).	=3rd mag.* .....	.....	Swift .....	.....
	11 11 51 p.m.	Birmingham ..	=3rd mag.*	White	0.75 second ...	From π Cassiopeiæ to β Pegasi.
	11 11 57 p.m.	Ibid	=2nd mag.*	White	0.5 second ...	From ν Cassiopeiæ to i Andromedæ, and $5''$ further.
	11 11 58 p.m.	Ibid	=1st mag.*	Deep blue ..	0.5 second ...	Centre of path at ζ Arietis.
	11 11 59 p.m.	Ibid	> 1st mag.*	Deep blue ...	0.75 second ...	$\alpha = 37^\circ + 28^\circ$ to $37^\circ + 22^\circ$
	12 12 2 a.m.	Ibid	=3rd mag.*	Blue	0.5 second ...	Commenced at $\frac{1}{2}$ (α Arietis, α Trianguli).

Appearance; Train, if any, and its Duration.	Length of Path.	Direction; noting also whether Horizontal, Perpendicular, or Inclined.	Remarks.	Observer.
Left no streak				A. S. Herschel.
Left no streak				Communicated by A. S. Herschel.
Left a streak for 1 second				A. S. Herschel.
		Directed on a line from α Cygni to α Andromedæ.		Communicated by A. S. Herschel.
Left a streak	25°	Directed from ϵ Cassiopeiæ.		W. H. Wood.
Left a streak 2° in length	8°	On a line from β Cassiopeiæ to ϵ Cygni.		Communicated by A. S. Herschel.
		Towards α Aquilæ		Id.
				Id.
		Fell vertically		Id.
Left no streak		Directed from η Persel.		W. H. Wood.
Left a streak	25°	Directed from η Persel.		Id.
Left a streak about 8° long	8° or 10°	Directed from ϵ Cygni.		Communicated by A. S. Herschel.
Left no streak				Id.
Left a green streak for two seconds.		From Radiant R, ...	This meteor and the next appeared within 3 seconds of each other.	W. H. Wood.
Left a green streak for two seconds.		Directed from η Persel.		Id.
Left no streak	6° or 8°	Directed from χ Persel.		Communicated by A. S. Herschel.
Left a streak				W. H. Wood.
Left a green streak		Directed from η Persel, or from Radiant T ₂₃₁₄ .		Id.
The meteor flickered			Intermittent light	Id.
The meteor flickered		Directed from γ Persel.	Intermittent light	Id.
	5°	Directed from α Persel.	The particulars of many minute meteors seen on this night are omitted in the present list.	Id.

APPENDIX.

I. METEORS DOUBLY OBSERVED.

SEVERAL of the large meteors described in the foregoing catalogue having, from their extraordinary brightness, attracted the attention of observers at many places in England, as well as in neighbouring places on the Continent, to which the course of their aerial flight was more immediately directed, the comparison of the accounts affords, in some instances, approximate estimates of the real heights and distances of their luminous paths.

The course of the large meteor seen in central France on the evening of the 5th of September, 1868, although imperfectly determined by the English observations in Auvergne and at Geneva, must yet have been little less than 100 miles in length over the valleys of the Seine, the Yonne, and the Loire, north and west of the mountains of Côte d'Or and Auvergne, directed, apparently at no great inclination to the horizon, from north-east to south-west, at a height of upwards of fifty miles above the earth. In the absence of more complete descriptions of its apparent course, only the general direction of its real path and the nearest departments of France (Yonne and Cher) over which the meteor must have been conspicuous can be pointed out. The very distant observations of the same meteor at Aosta and Florence, however, indicate for the earlier portion of this meteor's flight a far more extraordinary length of course than is common among large fireballs. The following notice of a careful study of its real path and altitude will accordingly be read with more than ordinary interest. (See *Comptes Rendus* for August 2, 1869, vol. lxi. p. 326.)

"*Meteors.*—In a paper addressed last week to the French Academy of Sciences, M. A. Tissot examines the circumstances accompanying the passage of the remarkable bolis of the 5th of September, 1868. It was seen to pass over Belgrade, Laybach, Bergamo, Saulieu, Civray-sur-Cher, and Mettray*. At Bergamo, M. Zezioli found that in 17 seconds it described an arc, the extremities of which were respectively, in right ascension 17° , N. declin. 3° ; R.A. 202° , N. decl. 27° . At Trémont, M. Magnin, while observing Jupiter, had at one moment both the planet and the fireball in the field of his telescope. M. Mugnier at Saulieu and M. Badiller at Civray-sur-Cher both saw it in the zenith. Letting alone the two latter data, which are somewhat uncertain, there is just enough left to enable us to determine the position of one point of the meteor's path, and those of two right lines between which it moved during a known space of time. From this may be obtained the *minima* of velocity with respect to the earth and the sun, and which are respectively 80 and 71 kilometres per second. Now were the orbit described elliptical, or even parabolic, the velocity could not exceed 42 kilometres; there can therefore be no doubt that the trajectory was an hyperbola. This is, we believe, the first time that the path of a fireball has been ascertained from reliable mathematical data. From this starting-point M. Tissot proceeds to correct the doubtful observation of Civray, and finds that the meteor passed over that place at a distance of $3^{\circ} 12''$ from the zenith. The lowest altitude of the bolis was 111 kilometres; the eccentricity of the geocentric hyperbola was 124, and its two asymptotes formed an angle of one degree

* M. Tissot states that the path of the meteor was vertically over those places; its altitude at its disappearance over Mettray, in Indre et Loire, 798 kilometres (496 miles) from Bergamo, being 307 kilometres (191 miles), and the lowest altitude of its course was 111 kilometres (69 miles). The meteor therefore shot upwards (!); and the whole length of its course from Belgrade, in Servia, to Mettray was nearly 1000 miles!

only. Our author now has sufficient data to calculate the orbit of its heliocentric motion, and finds its elements as follow: Longitude of ascending node $343^{\circ} 28'$; obliquity to ecliptic 68° ; angle of transverse axis with line of nodes, $87^{\circ} 32'$; eccentricity 2.59; semiaxis major, in parts of mean terrestrial radius taken as unity, 0.20; period of perihelion passage, 1868, Sept. 25th, 19 hours; velocity at perihelion 100 kilometres per second. Motion retrograde. The meteor merely passed through our solar system; twenty days after it made its appearance it passed through its perihelion, the distance of which from the sun is about the same as that of Mercury. The bolis is now further away than Saturn, but has not yet got beyond Uranus."

From a comparison together of some of the principal descriptions of the detonating meteor of the 7th of October, 1868, Mr. W. H. Wood considers that its point of first appearance was between 80 and 100 miles above Avranches, in the north of France, and that it descended in about five seconds, with a luminous course of about 180 miles, to a height of not more than eight miles above the English Channel, twenty miles from Hastings, in the direction of Dieppe. The detonation distinctly heard at Paris would, in this case, arise from an earlier portion of the meteor's flight. In relation to the height and other particulars of this meteor, the following remarks of the Abbé Lecot, of Noyon (*Les Mondes*, vol. xviii. p. 333), proceeding upon the basis of good observations, deserve attention.

"The principal remarkable feature of the fireball of the 7th of October, 1868, was its vast volume, much larger than that of any other meteor seen for many years. Two other circumstances appeared also to be of some important interest; viz. 1st, the immense distance to which the series of detonations was heard over an area of more than eighty leagues (190 miles) in width, incomparably surpassing the distance to which the loudest claps of thunder, or the discharges of the largest cannons can be heard. If, moreover, the statements of the majority of the observers may be trusted, the interval between the bursting of the meteor and the sound of the report was so great that the phenomenon must have taken place at a prodigious height. Less than five minutes cannot be allowed, on the most moderate estimation, from the explosion of the meteor to the arrival of the first sound of the report; and this would imply a distance of more than twenty-five leagues (sixty miles). Taking into account the direction of the meteor as seen by the observers, it would be difficult to admit a height of less than twenty leagues (forty-eight miles). This height is confidently within the limits which it would be necessary to assign to it when the greater number of exact descriptions of the meteor given by competent observers are taken into the account.

"The second peculiarity which appears hitherto to have been overlooked is that the meteor was not solitary, but appears to have been connected with a long list of similar appearances, which have been more numerous than ordinary at this season of the year. Last night (October 19th), on two occasions, about 8 and 10 p.m., I saw each time, in less than two minutes, five bolides of considerable brightness, leaving behind them a persistent streak, and moving from south-east to north-west. Their apparent brightness was about that of the planet Jupiter. On every previous evening since the 8th of October, when the sky was clear, I have been astonished at the number of shooting-stars that have presented themselves, generally without my paying any particular attention to record their appearance."

By extending backwards some of the given apparent paths, Mr. Wood

infers that the direction relatively to the earth, or the apparent point of radiation of this great meteor, was probably the radiant τ , a general centre of divergence of shooting-stars near α and γ Pegasi during the months from July to November.

A collection of fourteen original accounts of the appearance of the great daylight meteor of the 3rd of November, 1868, was carefully examined by Mr. Wood, to determine as accurately as possible its real path. A radiant-point, or general vanishing-point of the apparent paths prolonged *backwards*, near Arcturus, is pretty clearly indicated as the most probable direction from which the meteor actually approached and entered the earth's atmosphere. Assuming this direction as established, and the apparent points upon its path observed by Mr. Wood at Birmingham as certainly very near approximations to the true positions of the meteor at its first and last appearance, the comparison of the remaining observations with these first assumptions regarding the computed path enables the latter to be at least provisionally fixed with moderate precision. The point of first appearance of the meteor was seventy miles over Cuckfield, in Sussex, and its point of disappearance twenty-five miles over Herne Bay, in Kent. The whole course of about eighty miles, performed in about three seconds of time, was directed from the west-south-west, descending at an inclination of about 35° to the horizon.

Should the real course of the meteor be assumed to be more nearly from west to east, the apparent radiant-point would be nearer to ϵ Virginis than to Arcturus; and preserving the same place of first appearance, the point of disappearance will be found to be at a height of about thirty miles over the neighbourhood of Calais.

Meteors of November 14th, 1868.—From a large number of meteors observed in the United States of America on the morning of the 14th of November last, Prof. Newton has selected several instances of meteors of conspicuous brightness, which were simultaneously observed by observers at distant places. The results, accompanied by two excellently executed plates of the persistent streaks, some of which presented peculiar features, are given in the 'American Journal of Science' for May 1869 (vol. xlvii. p. 399), and lead to the supposition, from the observed motions of translation and distortion of form of some of the streaks, that a northward current of the upper air prevailed below an altitude of about fifty-four miles, and that above this level, to a height of about sixty miles, a current of air existed moving towards the south, succeeded, at a greater height, by another current moving in a northerly direction.

The double appearance of the streaks observed with the telescope in some of the meteors of the shower suggests the conjecture, entertained by Prof. Newton, of an actual duality in the meteor itself; and a very possible analogy may thus evidently be recognized among the November shooting-stars to the double or multiple character, which is a common feature among the detonating and stone-producing meteors.

1. Meteor and meteor-streak observed at Newhaven &c. at 1h. 12m. A.M. New York time (see Catalogue). "The central point of the cloud may be regarded as fifty-four miles high, over N. lat. $40^\circ 43'$, and W. long. 76° , and its course S. 78° W., with an angle of depression of 20° upon the horizon of the places beneath it. The heights of its eastern and western ends were fifty-nine and forty-nine miles, or ninety-five and seventy-nine kilometres." In the earlier part of its course the meteor "passed the meridian of Haverford at a height of about sixty-eight miles, but may have been visible before it reached that point. . . . A note in his observation of the meteor at Pali-

sades, by Mr. Gilman, would imply a first altitude of eighty-five or ninety miles. This estimate, however, is not to be taken strictly."

2. Meteor and meteor-streak observed at Fern Lodge Observatory, Palisades, and at Stamford, Conn., at 2h. 48m. A.M. New York time. Although the base-line and the corresponding parallax are small, the two observed paths agree well together, and give an elevation of fifty-two miles for the end of the track, and sixty-five for the beginning, with a length of path of twenty-seven miles. A portion of the luminous streak, which in the field of view of a telescope magnifying forty times appeared double, and terminated by an oval cloud, was, allowing for the inclination and diameter of the field of view, 0.89 mile in length.

3. Meteor and meteor-streak observed at Portland and at Boston, U.S.A., at 3h. 51m. 30s. A.M. Portland time. A parallax of 53° upon the base-line of 121 miles gives for the height of the meteor, at a point near the beginning of its path, seventy-seven miles. The length of the luminous cloud, which gradually curled up and floated northward as it faded, remaining visible at Boston for three minutes, must have been ten miles.

4. Meteor observed at the same stations at 5h. 6m. A.M. Portland time. The altitude of this meteor at disappearance was about forty-eight miles. Its first appearance, judging from observation, was at a height of nearly 150 miles; but the track was so near to the radiant, that a difference of three or four degrees in the apparent length would reduce the first altitude below 100 miles.

5. Meteor and meteor-streak observed at Newhaven and at New York by Professors H. A. Newton and A. C. Twining, at 5h. 6m. 45s. A.M. Newhaven time (see Catalogue). The altitude of the beginning and end of the visible path of the meteor is, from these observations, eighty-five and sixty miles respectively. The motions of the train seem to indicate an upper current from the north above that from the south, which was shown by the motions of the train of the meteor of 1h. 12m. A.M. New York time.

6. Meteor and meteor-streak observed at Boston and Fairhaven, &c., U.S., at 5h. 30m. 30s. Boston time. The meteor left a streak, which at Boston remained visible for seven minutes, drifting northwards; and at Fairhaven it also remained visible as a pale cloud for five minutes, widening and becoming nearly circular and larger than the full moon. The observed paths agree very well with the necessary conditions, and indicate an altitude of about fifty-nine miles for the lower part of the cloud. The northward motion of the cloud showed that it did not penetrate through the upper into the lower current, which swept away southward the lower part of the train of the meteor at 1h. 12m. A.M. New York time.

1868, December 10th, 10h. 57m. P.M., London, and Ackworth, Yorkshire (see Catalogue). The resemblance between these two meteors in time and other particulars of their appearance, although singularly close, is only accidental, as the difference of the positions of their apparent paths at the two places does not agree with that which would be produced by the effect of parallax.

1869, May 31st, about 11h. P.M., Cambridge and Paris, &c. (see Catalogue). Among the many descriptions of this large detonating fireball, the apparent path is indicated at very few places with precision. An approximate determination of its real path by means of the reference to certain stars contained in the careful observations by Mr. Atchison at Cambridge, and by M. Robinet at Paris, leads to the result that the meteor first appeared at a height of about seventy miles above Eastbourne in Sussex, and disap-

peared about twenty miles above the English Channel, halfway between North Foreland and the opposite coast of France. The distance of this course, about fifty-five or sixty miles from Hawkhurst, Wrotham, and the other places in Kent where the detonation was distinctly heard at an interval of about five minutes after the meteor's disappearance, affords a verification of its correctness, while it is in good agreement with the apparent course of the meteor as observed at Brussels. The direction of the meteor from near ξ (in the spear-hand) of Boötes is probably an outlying example of the occurrence of the Radiant Q., in Corona, of shooting-stars during the greater part of the months of May and June.

1869, July 16th, 11h. 35m. p.m., London, Hawkhurst, and Beckenham (see Catalogue). The small parallax indicated by the observations at the two latter places of the point of disappearance of the meteor "near the star ϵ Pegasi" may partly be attributed to the great height of the meteor, which perhaps prevented any sound of its explosion from being heard, and partly to the direction of its apparent path, being at both stations nearly parallel to the straight line joining the two places of observation. The descriptions of the meteor's course at London are not sufficiently exact to afford any confirmation of this result. A similar meteor observed nearly at the same hour on the same date, in 1861, was likewise found to disappear at a great height (sixty-five miles) above the surface of the earth (see Report for 1862, p. 77).

1869, August 9th, 10h. 59m. p.m., Hawkhurst and Birmingham (see Catalogue). The resemblance of these meteors, like that of the two meteors almost simultaneously observed on the 10th of December last, is only accidental, the apparent paths at the two places not satisfying the necessary conditions of identity, although the two meteors approximate to each other very closely in their remaining features.

II. AÉROLITES AND LARGE METEORS.

a. *Aérolites*.

Daniel's Kreil, Grigua Territory, South Africa, March 20th, 1868.

The fall of the meteorite was witnessed by a native, who picked it up whilst still warm. The specimen, which weighs 2 lbs. 5 oz., was brought to England by a well-known mineralogist, Mr. J. R. Gregory, and analyzed by Professor Church. In composition it is a meteoric stone, containing much free iron disseminated through its mass, together with some troilite and schreibersite. The following is Professor Church's analysis of the *aérolite*:

Nickel-iron	29.72
Troilite	6.02
Schreibersite	1.59
Silica and Silicates	61.53
Oxygen &c. and loss	1.14
	100.00

A new mass of meteoric iron, from South Africa, was also noticed by Mr. Gregory. It fell in 1862 at Victoria West, and is preserved in the Museum at Cape Town. (Quarterly Journal of Science for January 1869, No. xxi. p. 133).

Pnompehu, Camboja, Cochinclina, 1868, between June 20th and 30th, about 3^h p.m. (local time).

The meteorite separated into three pieces, of which one fell at the door of

the king's palace, the other two pieces were picked up at a considerable distance. The first piece, forwarded to France by M. Lafon, Naval Surgeon, residing at Pnompehu, is pyramidal, weighing about 2 lbs. (1 kilogr.). It is covered with a black shining crust $\frac{1}{50}$ inch in thickness, in which nickel-iron is scattered in fine grains. The fracture is granitic, and speckled with dark spots. The substance of the meteorite dissolved in muriatic acid leaves a residue of graphite and of crystalline silicates. A portion was sent to M. Peyromol, Professor at the medical school at Rochefort, for more exact analysis. ('Les Mondes,' 1868, Nov. 20th.)

Namur, Belgium, 1868, July 5th, 11^h 45^m p.m. (local time).

During a violent storm a fireball fell on the roof of a house at Namur, and broke a tile. The fall coincided with a clap of thunder. The only residue found of the ignited body was a small meteorite weighing about a third of an ounce (10 grammes); some grains of which were detached for analysis, and the remainder now weighs 137 grains. It is entirely covered with a slight crust of olive-colour speckled with bright-yellow, but not crystalline-looking points, giving evidence of its exposure to a glowing heat. The interior substance is a friable dark-grey cinder, interspersed with black and yellow crystals, but without metallic grains. The density, 3.0004, is rather less than that of ordinary aërolites. It exhibits opposite magnetic poles at the two ends of its longest axis, and is highly magnetic. Attacked by hydrochloric acid it is partly dissolved, disengaging sulphuretted hydrogen, and leaving a pretty abundant residue containing graphite and free sulphur. The solution is found by the ordinary tests to contain iron, nickel, and chromium. ('Les Mondes,' 2nd ser. vol xviii. p. 332.)

Ornans, Doubs, France, 1868, July 11th.

The following extract from a French newspaper of September last, announces the fall of an aërolite in central France.—“On the 11th of July in the present year” [1868] “a meteorite fell at Ornans in the Department of Doubs. M. Pisani has submitted it to analysis, and he finds that it contains a very small quantity of nickeliferous iron, a small quantity of chrome-iron-ore, and magnetic iron-pyrites; it is besides very rich in peridot. Its structure is friable and porous, and its general aspect is of a deeper grey colour than is commonly observed in aërolites.” (See M. Pisani's analysis, in 'Comptes Rendus' for Sept. 28, 1868, vol. lxxviii. p. 663.)

Sanguis, Mauléon, Basses Pyrénées, 1868, September 7th, 2^h 30^m a.m. (local time).

After a meteor of the usual appearance a report was heard as far as Irun, on the Spanish border, 50 miles distant from Sanguis, where a meteorite weighing 4½ lbs. (2 kilogr.) fell into a small stream, 30 yards from the church, and broke into pieces. The pieces, which were further broken by those who found them in search of a supposed hidden treasure, were sent to the Museum of Geology in Paris, and analyzed by M. Stanislas Meunier. They closely resemble those of the meteorite of Casale, which fell (on the 29th February) six months and seven days before the present occurrence, appearing thereby to indicate two nodes of this meteoric orbit, intersecting the earth's orbit at 180° apart. The siliceous mass contains grains of nickel-iron, troilite, and chromite. (Report of M. A. Daubrée, 'Comptes Rendus' for Nov. 2, 1868; and 'Les Mondes,' Nov. 5th, 1868.)

1869, January 1st (morning).

Stonefall at Lake Malar, Upland, Sweden. ('Bulletins de l'Association Scientifique de France,' No. 105.)

Krähenberg, near Zweibrücken, Bavaria, May 5th, 1869, 6^h 30^m P.M.
(local time).

A specimen of this stonefall is in the Mineralogical Museum of Vienna.—
(Communicated by R. P. Greg. See also the Report on this meteorite by Dr. Neumayer, in the 'Proceedings of the Sections.')

Kernouvé, Cléguerce, Morbihan (Vendée), S. France. (Comptes Rendus,
No. 25, 1869.) May 22nd, 1869, 9^h 45^m P.M. (local time).

Stonefall after a brilliant meteor, which was seen at l'Orient, and at Vanues by M. Arondeau, leaving a long streak, and followed by a violent detonation. ('Bulletins de l'Association Scientifique de France,' Nos. 123 and 124.)

A large meteor, casting a bluish glare over the whole town, was seen in a northerly direction from Vannes, and was followed in 2½ or 3 minutes by a violent explosion, which shook the doors and windows of the houses. A meteorite, which appears to have been of conical shape, and to have weighed about 160 lbs. (English), struck the earth, at Kernouvé, a few yards from a young girl, who was the only witness of its fall, and it penetrated a little more than a yard into the ground. On the following morning it was dug out, broken in pieces, and the fragments were distributed among the villagers as mementos of a stone supposed to have fallen from the moon. Unable to disabuse its possessors of the supposed value of the relics, Professor Felix Pisani, of Paris, at considerable expense, succeeded in securing possession of almost the entire aërolite for his mineral cabinet, where the larger half is now destined for one of the European museums. A specimen weighing 32 lbs. he presented to the Paris Academy, with a careful analysis of the meteorite. The interior of the stone presents a dark grey granular mass, with iron-pyrites, and much metallic iron in bright grains, some of them a few millimetres wide, and others like thin veins or filaments scattered through it. The iron-pyrites, although magnetic, is not attracted by the magnet, and the metallic iron is thus easily separated from it. The entire meteorite is highly magnetic, and its specific gravity is 3·747. Its substance is fused by the blowpipe to a black magnetic bead, in which the spectroscope reveals the presence of sodium and calcium. It is partly attacked by muriatic acid: and a specimen thus treated offered to M. Pisani the following proximate chemical analysis:—

Nickeliferous iron	20·5
Magnetic iron-pyrites (Fe ₇ S ₈)	5·45
Silicates soluble in muriatic acid	34·6
Silicates insoluble in muriatic acid	40·22
	100·77

b. *Large Meteors.*

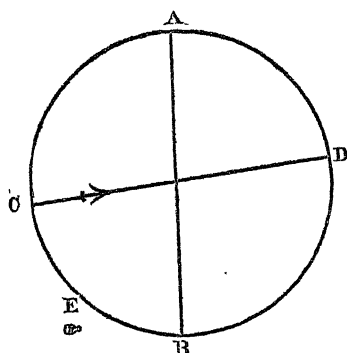
September 5th, 1868, 1^h 4^m P.M. (G.M.T.). Passage of a black body across the sun's disk.

On the same date as that of the large meteor seen at Geneva and in Central France (see Catalogue), Mr. G. Forbes communicates the following observation of a black body seen to transit the sun's disk at Pitholetrie, in Porthshire.

The sun's disk was projected on a white screen with a 2¼-inch achromatic

(of the late Mr. Dolland), magnifying about 60 times. A B, in the figure, is the projection of the vertical line; C D is the path of the meteor. "It was

Fig. 1.



not round, but shaped like E, the pointed end moving first. I was at the time watching a faint spot near which it passed, and it was much blacker than the spot. It took about $1\frac{1}{2}$ second to cross. I also drew the apparent size of the meteor and of the sun at that moment. By this means I find its apparent diameter to be $27''$ approximately, *i. e.* greater than the mean diameter of Saturn, and less than that of Jupiter. To have moved so slowly it must surely have been beyond the limits of visible meteors; and if at so great a distance, how great must its size in all likelihood have been!

"I have here taken for granted that it was a meteor, which some may question. Its motion was perfectly steady, quite unlike a bird crossing the field of view, which I have often seen. Another person was watching the spot with me at the time, so that there is corroborative evidence. I was enabled to take the time, position, shape, direction of flight, apparent size of the meteor (as a fraction of the sun's diameter), all except the duration, with great exactness. I may mention about the spot, that it was *quite* in focus for very distinct vision."

Kansas, U.S. America, June 6th, 1868, $11^h 40^m$ A.M. (local time).

At Manhattan a meteor was first seen in the western sky at an elevation of about 60° , descending at an angle of 75° to the horizon, and leaving a luminous streak which remained visible nearly a minute. The nucleus, of a vivid pink colour, was about $15'$ diameter. It fell in less than one second to within 12° of the horizon, where it burst, and thence descended in a double stream of fire. About $4\frac{1}{2}$ minutes afterwards a double report, like 12-pounder cannons at a distance of a mile, was heard. A light-blue cloud remained at the point of explosion, $1\frac{1}{2}^\circ$ long and nearly 1° wide, which remained visible, without much change of shape, until it was obscured by cirro-cumulus clouds. The report was heard over an area 120 miles in width, and the meteor was seen at Topeka, Marysville, Forts Harker and Zarah, and at other very distant places. Its flight was apparently from south to north.

Height of the meteor when first seen	81 miles
Height when it exploded	12.5 "
Length of the luminous persistent cloud	1.44 "
Breadth of ditto	0.96 "
Diameter of the nucleus	1890 feet
Distance of the explosion from the place of observation..	58 miles

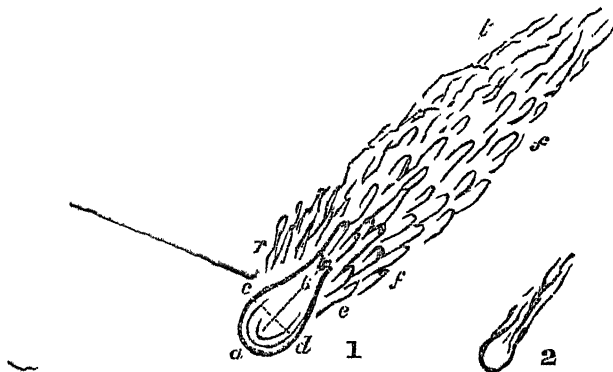
The above measures of the meteor's course are calculated by Professor Mudge, of the Agricultural College of Kansas, who adds that the meteorite must have exploded over the country halfway between the Republican and Solomon Rivers. This district has few inhabitants, and no aërolite has yet been picked up. ('American Journal of Science' for Nov. 1868, 2nd ser. vol. xvi. p. 429.)

Birmingham.—Large meteor seen in daylight, Nov. 3rd, 1868, 3^h 17^m P.M.

Mr. Wood's description of the meteor (see Catalogue) is accompanied by the following careful drawing and explanations:—

"The meteor was pear-shaped, the rectangular diameters being $\frac{3}{4}$ and $\frac{1}{2}$ the diameter of the moon (fig. 1). The body, brilliant white in front, and ruby-red near the tail, flickered considerably in transit, and diminished towards extinction, as represented in the drawing (fig. 2). Red flames, or the substance of the meteor, issued from the nucleus, and extended towards the tail one degree, as shown in fig. 1. The tail, 15° long, resembled ordinary smoke in sunshine; only a small section of it is represented in

Fig. 2.



Great daylight meteor of November 3rd, 1868, as seen from Birmingham. Diameter $ab=24'$; $cd=14'$. ff , Red flames (or particles of the meteor)=1°. Space abc of nucleus ruby-red. Space rac of nucleus brilliant white. t , portion of tail 15° long, bluish-white, smoke-like, lasting $1\frac{1}{2}$ second.

Fig. 1. Size at appearance.

Fig. 2. Relative size at extinction, devoid of lustre.

the figure. The nucleus preserved its intensely white light until near the last 5° of its course, when there was a perceptible diminution in its lustre; its size was then about equal to Venus. At the time of collapse I thought it dark red, or non-luminous, probably from the contrast with sunlight, as the effect of the sun's presence would be to deprive the meteor of the usual bordering rays of light.

"The same object at night would certainly have appeared much larger, and have produced an extraordinary illumination over England. The path appeared slightly undulating, if it were not an optical illusion produced by the fluctuation of its light.

"A few clouds were rapidly driving across from the W.S.W., and the sun shone brightly; yet the meteor stood prominently out, in bold relief, on the greyish background of the sky."

The following additional notice of this large meteor is communicated by Sir J. Herschel, Bart. Extract of a letter from H. Griesbach, Esq.

"Travelled from Worcester to Morton on Thursday last" [Nov. 4th] "with a lady and gentleman who reside at Morton. They told me that on Wednesday last [Nov. 3rd] about 3 o'clock, they were walking from their residence at Morton to call on some friends at Toddenham, when they saw a most brilliant meteor which fell to the earth about a furlong from them. They described the light from the meteor as extremely bright and white, the sun shining brightly at the same time. They did not hear any noise from the motion of the meteor. The gentleman said he thought that he should be able to find the spot where the meteor fell, and promised to take two of his men to search for some relic."

The meteor was also observed at Southam, South Warwickshire, as a large fiery body, travelling in the direction of the wind (which was from W.S.W.: see Weather Reports).—*Birmingham Gazette*, November 7th.

Bolides observed in France, 1868–69.

M. A. Guillemin, author of the French work on Astronomy '*Le Ciel*,' communicates the following notes of observations of large meteors contained in the Numbers of the weekly '*Bulletins*' of the '*French Association for the Advancement of Science*,' of which two annual volumes, under the active presidency of M. Le Verrier, have now appeared:—

	No.
1868. Sept. 5th.—Notes by Messrs. Denza and Schiaparelli	108
1869. Jan. 1st.—Swedish aërolite, observed at Stockholm, Upsala, &c.	105
" Feb. 2nd.—Bolide at Bordeaux: M. Rousanne	} 108
" Feb. 8th. " Nancy: M. A. Tissot	
" Feb. 24th. " Marseilles: M. Borelly	} 110
" March 2nd. " Bordeaux: M. Rousanne	
" April 28th. " Pont Pierre (Moselle): M. Richard	.. 120
" May 22nd.—Aërolitic meteor observed at L'Orient and Vannes.	
Fall of stones at Cléguère	123
" May 22nd.—Fragments presented to the French Association	124
" May 22nd.—Details of observation at Vannes: M. Arrondeau	126
" May 31st.—Bolide at Paris: M. Robinet (see Catalogue)	.. 124
" May 31st.—Seen also at Albert (Somme); M. Comte; and at Pontarmé, near Senlis	126
" June 17th, 8 ^h 34 ^m p.m.—Bolide at Marseilles: M. Borelly.	
Seen also at Narbonne and Aix-les-Bains	ibid.
" June 17th.—The same at Annecy (Savoy), at Montpellier, Perigueux, and Sarlat (Dordogne)	127
" June 18th, 1 ^h 12 ^m and 1 ^h 50 ^m a.m.—Two Bolides observed at Marseilles: M. Borelly	126

In the '*Zeitschrift der österreichischen Gesellschaft für Meteorologie*,' vol. iii., large meteors are recorded as having been observed at certain places in Germany during the nights of the 17th of September and 17th and 26th of October, 1868.

In continuation of his former list, Mr. Greg has added the following supplementary Catalogue of large meteors observed in recent years to the numerous records of such occurrences contained in the Appendix of the last Report (for 1868), and collected in similar lists in the Reports for 1860 and 1867.

1869.

Catalogue of Aërolites and Meteors. By R. P. Greg.—Supplement No. I.

Year.	Day of month.	Locality.	Size &c.	Observations.
1842.	Jan. 29...	Eutin	large	Whitish; 7 seconds. Greenish.
1844.	Dec. 9...	Hamburg	> Venus	
1845.	Jan. 26...	Flottbeck	large	
"	Aug. 9...	Bilk .....	.....	
1846.	April 21...	Huatasco		Whitish; 7 seconds. Greenish.
"	July 29...	Rhine-land		
"	Nov. 28...	Bonn		
1847.	June 2...	Do.		
"	Sept. ...	Piræus.	large	
1848.	Mar. 24...	Frankfort		
"	July 13...	Bonn		
1850.	Feb. 17...	Do.		
"	21...	Lüdenscheid		
"	Aug. 29...	Nauplia		
1851.	Aug. 14...	Melfi		Two seen.
"	16...	Rastenburg		
"	26...	Grieskirchen		
1852.	June 8...	Rastenburg		
"	Oct. 16...	Eutin		
"	Nov. 27...	Bonn		
"	Dec. 2...	Jena.	large	
"	18...	Bonn		
1853.	Jan. 26...	Osnabrück		
"	27...	Süchteln .....	.....	
"	Feb. 26...	Bonn		And other places.
"	July 5...	China		
"	Aug. 10...	Switzerland		
"	Oct. 28...	Holland		
1854.	Jan. 3...	Wels	large	
"	Feb. 3...	Stromboli		
"	Mar. 1...	Aargau		
"	Aug. 24...	Blansko		
"	Oct. 5...	Naples		
"	Nov. 2...	Cronstadt	large	
"	16...	Hamburgh	do.	
"	Dec. 2...	Lemberg	do.	
1855.	Mar. 27...	Thurgau		Greenish.
"	May 3...	Naples		
1856.	May 25...	Petersburg		
"	Aug. 9...	Olmütz .....	.....	
"	Oct. 19...	Triest		
"	Nov. 15...	Troppau		
"	Dec. 14...	Olmütz		
"	27...	Do.		
1857.	Feb. 16...	Holland	large	
"	Mar. 24...	Smyrna		
"	29...	Bohemia	large	
"	May 18...	Olmütz		Greenish.
"	June 6...	Do.		
"	Aug. 15...	Do. ....	.....	
"	Sept. 13...	Wimpassing		
"	Oct. 7...	Olmütz		
"	Dec. 18...	Oldenburg .....	.....	
1858.	Jan. 15...	Troppau		
"	15...	Navoina		
"	20...	Olmütz	large	
"	22...	Görmöver		
"	23...	Menyhazza		

TABLE (continued).

Year.	Day of month.	Locality.	Size &c.	Observations.
1858.	April 24..	Van Diemen's Land.	= $\frac{1}{3}$ moon	Bluish white; 4 secs., 8 p.m.
"	Aug. 5..	Olmütz		
"	Nov. 12..	Oxford		
1859.	Jan. 4..	Holstein	large	
"	4..	Athens .....	.....	(Julius Schmidt* &c.)
"	June 27..	Do.		
"	Oct. 9..	Do. ....	.....	12 secs., greenish.
"	Nov. 2..	Do.		
"	6..	Do.		
1860.	June 16..	Do. ....	.....	Greenish.
"	Dec. 23..	Do.		
1861.	April 5..	Coblenz		
"	June 30..	Athens		
"	July 12..	Do.		
"	Sept. 1..	Do.		
"	27..	Do.		
"	Oct. 31..	Dara, Arcadia.....	large	5.30 p.m.
"	Nov. 1..	Athens		
1862.	Feb. 18..	Algiers		
"	Mar. 31..	Athens		
"	25..	Van Diemen's Land..	= $\frac{1}{2}$ moon	Streak 10"; greenish; 10 p.m.
"	May 16..	Athens		
"	21..	Do.	large	Streak 20".
"	June 29..	Do.		
"	July 16..	Levant?		
"	20..	Athens	large	7 p.m.
"	Aug. 16..	Arcadia		
"	Sept. 16..	Athens		
"	Oct. 12..	Do.	large	6.15 p.m.
"	26..	Vienna		
1863.	Feb. 26..	Geneva .....	.....	Bluish, 15 secs.
"	Mar. 23..	Vienna		
"	May 31..	Washington		
"	June 6..	Oxford		
"	Sept. 7..	Hungary		
"	Oct. 1..	Athens		
1864.	May 12..	Psara, Greece	large	
"	Aug. 2..	Kephissia, Greece .		
"	22..	Do.		
"	30..	Athens		
"	Sept. 6..	Do.		
1865.	Mar. 30..	Tyrol .....	.....	Streak 10".
"	April 12..	Palermo		
"	29..	Somersetshire	large	8.15 p.m.
" *	July 5..	Natal	large	E. to W.; detonation in 2 seconds.
"	Aug. 4..	Jutland		
"	20..	Athens .....	.....	Streak 15".
"	Sept. 12..	Do.		
"	20..	Aube, France	large	Detonated in 5 minutes, after divid- ing into two halves; 5 a.m.
"	24..	Kent .....	.....	7.48 p.m.
"	Oct. 18..	Athens		
"	24..	Do.		
"	Nov. 27..	Essen, Prussia		
1866.	Jan. 9..	London, &c. ....	.....	Also at Greenwich.
"	22..	Dantzic	=moon	7.18 p.m.
"	Feb. 2..	Maidstone		
"	June 2..	Eubœa		
"	24..	Derby	= $\frac{1}{4}$ moon	11 $\frac{1}{2}$ p.m.; 60° in 2".

TABLE (continued).

Year.	Day of month.	Locality.	Size &c.	Observations.
1866.	July 5...	Kent	noon	In sunshine; large.
"	21...	Athens.....		
"	Aug. 8...	Corfu		
"	24...	South Australia	large	
"	Sept. 9...	Athens.....		
"	Oct. 19...	Holyhead and Dublin	5' d	Brilliant; S. to N.; 3 a.m.
"	24...	Kildare, Ireland.....	large	4.40 p.m.; moved slowly.
"	Nov. 6...	Sussex	3> Venus	Very slow; sparks.
"	9...	Buckinghamshire		Lighted up the sky; 8.40 p.m.
"	13-14	Athens.....		3 very large ones.
"	"	London, England	$\frac{1}{2}$ - $\frac{3}{4}$ moon	Several very large ones.
"	"	Nashville, Tennessee.	= sun	4 a.m.; moved S.W.; detonated loudly.
"	"			
"	* Dec. 6...	Santander, Spain		Stone-fall (not Nov. 30?)
"	8...	York	= $\frac{1}{2}$ moon	Red; 1 sec.; 18° path; 8.47 p.m.
"	10...	Do.	= $\frac{1}{2}$ moon	
"	12...	Kishnaghur, India		
"	12...	York	= $\frac{1}{2}$ moon	
"	12...	Ireland		
"	12...	Constantinople; Athens.	large	
"	15...	Brest, France.....	do.	
"	* 14...	Alderly, Cheshire	do.	Followed by a loud detonation.
"	30	Athens.		Also seen at Manchester.
1867.	May 6...	London	3> Venus	Kite-shaped, 7.50 p.m.
"	* June 9...	Scif, Algeria	10.30 p.m.	Stone-fall; no crust; meteor and detonations.
"	"	11... Switzerland; Paris...	= $\frac{1}{2}$ moon	Streak remained for an hour; direction N.W. to S.E., between 65 and 85 miles high; from over Dunkirk to over Cambray; detonated.
"	Aug. 19...	Dobbs's Ferry, New York, U. S.....		Elongated; divided into three.
1868.*	Jan. 30...	Pultusk, Poland.....		Stone-fall; regular shower, like that of l'Aigle in 1803.
"	"	... Dantzic and Poland..	= moon	Large meteor at 6.18 p.m., same as the last.—J. G. Galle.
"	* Feb. 29...	Alessandria & Casale; Piedmont.	11 a.m.	Stone-fall; detonation from a fiery cloud; 3 stones = 9 kilogrammes, 3'6 sp. gr.
"	29...	Chinavry, Italy	10 a.m.	Large fireball from S.W.
"	29...	Ditto?	11 $\frac{1}{2}$ p.m.	Large meteor, S. to N., horizontal.
"	* Mar. 20...	Iriqualand, S. Africa		Stone-fall (2 $\frac{1}{2}$ lbs.).—Quarterly Journal of Science.
"	* June 6...	Kansas, U. S. A.....	= $\frac{1}{2}$ sun	Fell down ver. 75°; 11.40 a.m.; heavy double explosion in 4 $\frac{1}{2}$ minutes from a light blue cloud, which was seen for 17" afterwards; report heard over 120 miles area; S. to N. Probably 12 $\frac{1}{2}$ miles high when it burst.
"	* Sept. 7...	Tardet, Basses Pyrénées.	2.30 a.m.	Stone-fall, meteor, and great detonation. N.W. to S.E.; sp. gr. of the stone 3.37.
"	Oct. 7...	London	large	
"	Nov. 3...	Rugby, Birmingham, &c.	= $\frac{1}{2}$ moon	Large meteor at 3 $\frac{1}{2}$ p.m. In bright sunshine.

III. STAR-SHOWERS.

1. *The August Meteoric Shower in 1868.*—Signor Francesco Denza, Director of the Observatory at Moncalieri, in Piedmont, has published a pamphlet of the observations made on the nights of the 9th–12th August in Italy, comprehending so no fifteen stations. It appears that the largest number to be seen by a single observer in one hour was at Florence, viz. 26·9 on the night of the 10th August, at 13^h–14^h. Three observers, under the supervision of Prof. Donati, registered :—

August.	10 ^h –11 ^h .	11 ^h –12 ^h .	12 ^h –13 ^h .	13 ^h –14 ^h .	14 ^h –15 ^h .	Totals.
9	45	40	30	30	42	187
10	64	70	88	98	83	403
11	63	46	48	31	35	223

Of these, about 5 per cent. on each evening were sporadic, or not Perseids. Out of these 813 meteors Prof. Donati classifies 164 as large ones, 221 of ordinary size, and 428 as small. As compared with the Perseids of 1867, the result appears, as reduced for the same days and hours of observation, for a single observer :—

	Aug. 9.	Aug. 10.	Aug. 11.	Totals.
1867	67·0	104·8	79·3	251·1
1868	62·3	134·3	74·3	270·9

From whence it does not appear that there was any great difference in the richness of this shower for the two years. Signor Denza gives the positions assigned to the radiant-point of these August meteors, as determined by competent observers, at 6 out of the 15 Italian stations, and the results are remarkably accordant :—

	R. A.	N. Decl.
Bergamo	0	0
Milan	43	57
Lodi	?	57
Moncalieri	45	56
Urbino	44	57
Palermo	45	56·5
Palermo	43·4	56·7
Mean or average.....	44·1	56·7

The position of the Perseid radiant, as determined by A. S. Herschel in 1863, was R. A. 43°·8, N. Decl. 56°·2 (Report for 1864, p. 98).

For the fifteen stations in Italy, the horary numbers, reduced for a single observer, gave as average :—

9 August	8·2
10 „	14·7
11 „	10·5
12 „	5·1

At Urbino Prof. Serpieri gives the radiant positions as follows :—

	R. A.	N. D.
9 August	41°0	57°5
10 „	45°0	56°5
11 „	44°5	56°5
Mean	43·5	56·8

The path of one meteor, observed at Moncalieri on the evening of the 9th, at 10^h 5^m, was curvilinear (*tortuosa*), and the light of another, at 10^h 12^m (Turin time), was intermittent. Bolides of considerable brightness were observed on the 7th at 9^h 15^m p.m., on the 9th at 9^h 35^m p.m., and a third on the evening of the 10th at 10^h 49^m p.m. The first, brighter than Venus, of a reddish colour, made its appearance at an altitude of 40° above the S.E. horizon, between α and δ Lyrae, and descended vertically with very slow speed to η Serpentis, near the same point of the horizon; it left behind it a most brilliant-white, persistent streak. The last of the three bolides was so bright as to illumine the clouds near which it passed.

At Bra, in Piedmont, two meteors were observed, with curved paths, on the morning of the 10th, at 12^h 20^m and 12^h 30^m A.M. On the same morning, at 12^h 53^m, local time, a bolide, more brilliant than Jupiter, of bright whiteness, was seen at the Observatory of the College at Rome, moving from the south towards the east. Madame Scarpellini, at Rome, saw a similar meteor on the evening of the 10th, at 10^h 50^m p.m., which was also seen by Prof. Pinelli at Civita Vecchia. The latter observed another bolide of equal brightness at Civita Vecchia on the morning of the 11th, at 1^h 53^m A.M.

At Palermo very brilliant bolides were observed by Prof. Tachini on the nights of the 5th and 6th of August, 1868 (*Bulletino Meteorologico del R. Osservatorio di Palermo*, vol. iv. Nos. 8 & 9).

At the Meteoric Observatory of the Luxembourg M. Chapelas-Coulvier-Gravier noticed the greatest frequency of meteors (1·3 per minute) on the morning of the 10th, between midnight and 1^h A.M. The number of meteors recorded during the night of the 10–11th was 237, of which 113 were of the 3rd magnitude, or brighter, and 49 left persistent streaks. A bolide presenting very remarkable features was observed at 11^h 27^m p.m. on the night of the 10th. The meteor was “conformable to the general direction of the meteoric current,” and moved slowly, as if resisted in its course, so that, instead of the usual spherical form, it appeared internally agitated, and assumed the form of a cone, with base foremost, from which the material of the meteor fell off in red sparks along the dazzlingly bright luminous streak. (*Comptes Rendus*, vol. lxvii. p. 498.)

Prof. Tachini, of the Royal Observatory of Palermo, in the ‘*Bulletino Meteorologico*’ of that Institution for August and September 1868, gives a very full account of the meteor observations made at that observatory on the evenings of the 8th, 9th, 10th, 11th, 12th of August, 1868. The number of meteors seen by four observers in three hours (after 10 p.m.), on the evenings of the 8th, 9th, and 10th August, were respectively 44, 101, 195; in two hours ten minutes on the 11th August 115 meteors, and in one hour and eight minutes on the evening of the 12th August 24 meteors. This would give a relative frequency of

14·7, 27·3, 52·7, 39·7, 13·3,

and would probably indicate a *maximum* frequency on the morning of the

11th August towards 7 A.M. This result was confirmed, it appears, by the observations made by the astronomers at Rome.

In all a catalogue of 393 meteors are given for these five evenings, with the precise time of observation, apparent magnitudes, and exact positions of the paths of each observation, determined by the fixed stars; as well as colours.

In the 1st quadrant.....	= 78
" 2nd "	= 112
" 3rd "	= 97
" 4th "	= 160

Professor Tachini himself observed, with the aid of his *meteorometre*, which he had made use of for the 14th-November meteors of the preceding year, and described in the Journal of the Observatory, No. 11 of vol. iii.

His observations in R. A. and N. Decl. were then drawn upon a celestial map, and the following results are given in relation to the radiant-point:—

Palermo, August 1868.	R. A.	N. Decl.	No. of observations.
8th	=41°0	+57°6	= 8
9th	=46°0	+56°5	=21
10th	=40°8	+56°5	=35
11th	=45°0	+56°5	=19
12th	=49°7(?)	+57°0	= 4
Means ...	=44°5	+56°8	Total 87

Another Table is given, showing the reductions of *all* the observations made during the five evenings by himself and the four other observers in reference to the radiant-point:—

R. A.	D.
43°5	+57°0
45°0	+53°0
41°0	+57°0
40°0	+57°5
47°5	+59°0
Means..43°4	+56°7

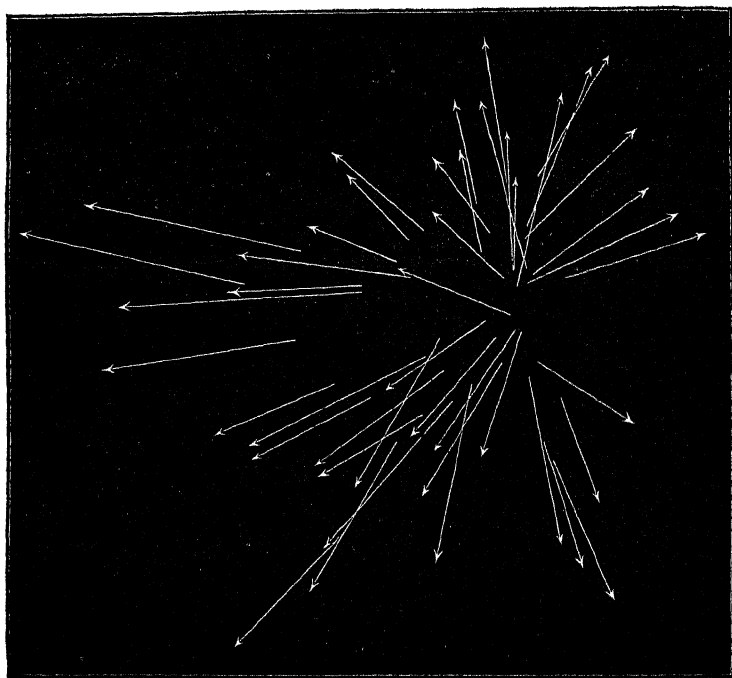
Rejecting the observations of the evening of the 12th August, on account of their comparative paucity, we obtain as the best average result for the radiant position R. A.=43°3, N. Decl.=+56°8; and this is probably a pretty accurate determination.

Other meteors were seen on these evenings, which may have belonged to other radiants; *five* seen on the evening of the 10th August had a radiant-point at R. A.=3°5', N. Decl.=+71°.

The trajectories of all were in straight lines, and the streaks of the meteors well marked, appearing as a slight or feeble residuum of the substance of the burning meteor itself, whose diameter generally appeared larger than that of the streak or train.

Prof. A. Serpieri, of Urbino, gives, in the monthly 'Bulletino Meteorologico' of the Osservatorio del Collegio Raffaello, occasional observations of meteors. On the evening of the 21st of May, 1868, the positions and times of seven-

teen are recorded in R. A., and N. Decl.; and a considerable number for the evenings of 23rd–26th of June.



Tracks of meteors recorded at the Royal Observatory of Palermo, on the 8–12th of August, 1868, showing the position of the radiant-point. By Professor Tachini.

Professor Serpieri, with three other observers, found that the horary numbers on the following evenings were,—

	No.
9th August	51
10th „	105
11th „	74

Each evening the chief radiant-point was near η Persei, with two minor ones near Camelopardus, at about R. A. = 40° , Decl. + $58^\circ.5$, and $49^\circ.5$, + $58^\circ.5$. The meteors on the evening of the 10th August appeared finer, and gave longer paths than those of the 9th and 11th August. There appeared to be a considerable number of meteors on each evening belonging to other radiants (or sporadic), most of which, however, seemed to lie around, as it were, the sides of a polygon, with the constellation Perseus itself a centre of them.

Prof. Serpieri considers that the radiant presented itself rather diffusely, taking into account all the meteors which passed near k Persei. Projected on a chart, the tracks approximately crossed each other.

On the	9th August,	from R. A.	46° to 36° ,	and Decl.	61° to 54° .
„	10th	„	„	50° to 40° ,	„ 54° to 59° .
„	11th	„	„	49° to 40° ,	„ 55° to 58° .

Taking the average of these positions,

		R. A.	Decl.
for August	9	4 ^h 1 ^m	+57° 5'
"	10	45	+56° 5'
"	11	44° 5'	+56° 5'

The average of 3 days... = 43° 5' 56·8

which agrees well enough with the result of Schiaparelli's and Zezioli's observations for this year.

At Milan, Prof. Schiaparelli considered the Perseids of August 1868 more conformable than usual; the declination of the radiant-point was determined more precisely than, perhaps, its right ascension, as about 57°. Zezioli, at Bergamo, found

R. A. = 43°, Decl. + 57°.

Signor Zezioli, of Bergamo, has also sent to Mr. R. P. Greg particulars of about 600 meteors seen in March and April 1868, most of which Mr. Greg has reduced upon the charts prepared by Mr. A. S. Herschel for the British Association, and the results as to radiants are given in the second edition of the *Atlas of Meteor Charts**.

At Rome, Mancini states the horary numbers for three observers thus,—

	No.
9th August	25
10th "	46
11th "	42
12th "	18

Mr. R. P. Greg, at Whitby, considered the principal radiant for the earlier part of the August shower (from 2nd August to 8th August) as very close to κ Persei, or about R. A. 44°, N. Decl. + 57°.

2. *The November Meteoric Shower in 1869.*—"Captain Donald of the 'Preston,' from Bombay to Liverpool, reports that on the 14th inst., when thirty-eight miles S.S.W. of Kinsale (N. lat. 51° 42', W. long. 8° 31'), from 2h. A.M. till after daybreak, meteors appeared to be bursting in every direction, like innumerable rockets flying across the heavens. The principal direction was from S.E. to N.W. The weather was rather overcast at first."—*Liverpool Mercury*, Nov. 28th, 1868.

From the logs of various vessels transmitted to him for analysis, Captain H. Toynbee, head of the Ocean-Meteorological Department of the Board of Trade, has kindly extracted, at the solicitation of the Committee, the following entries, in which the occurrence of this star-shower is noticed as having been observed at sea.

Extract from the log of the ship 'Spray of the Ocean,' Capt. P. Slaughter, from Bombay to Liverpool, "Nov. 14th, 1868, N. lat. about 15°, W. long. about 32°" [in the N.E. trades of the Atlantic Ocean].—"From midnight until daylight a continual succession of meteors; countless; many of them of great magnitude and brilliancy, their direction mostly from between N.E. and N.W. towards the latter point. Their tracks, also, mostly parallel to the horizon, at altitudes from about 10° to about 35."

Under the same date and hour, in a corresponding position of the S.E. trades, where no lightning is usually seen, an entry in the log of another vessel contains a memorandum of the appearance of constant lightning.

* These charts, containing 26 plates, can be obtained on application to Messrs. Taylor and Francis, Red Lion Court, Fleet Street, London.

In an excellent meteorological register kept on board of the ship 'Siberia,' between Boston and New York, by Captain Mostyn, there is recorded on the night of the 13th and early morning of the 14th of November, 1868, "Meteors glancing from east to west, at an average rate of five or six per minute, at times leaving a luminous track extending 15° or 20° , which remained visible 4 or 5 minutes. The night being perfectly clear gave an additional effect to the gorgeous display."

A good Weather-register kept by Captain C. T. Raymond, on board of the ship 'British India,' gives a description of the shower as it appeared to him in southern latitudes.

"November 13th, 1868, at 10h. 30m. p.m. in S. lat. $26^{\circ} 3'$, W. long. $27^{\circ} 37'$.—A perfect shower of shooting-stars commenced, and continued until the rising sun extinguished their light. It might be best compared to a shower of rockets; for, like them, they left long trains behind, moving confusedly in all directions, some falling perpendicularly, some obliquely, some horizontally describing curves, and some even slightly ascending. Some shone with a bright green light, exploding at last into many pieces, but without report; some with a dull red, and some with a faint yellow. It resembled in every respect a similar shower which I witnessed in Bombay, 14th November, 1866. At times the meteors fell as dense as snow-flakes.

"I could not detect any uniformity, either with regard to the point of the heavens whence they started, or whither they fell. Most fell perpendicularly, and with a prodigious velocity."

The following description of the meteoric shower in America, as observed at Haverford College, Pa., by Prof. Samuel J. Gummere, was received, at the time of its occurrence, by the Committee from Mr. B. V. Marsh:—

"Meteoric Shower, November 13–14th, 1868, as observed at Haverford College, Pennsylvania, ten miles west of Philadelphia. Latitude $40^{\circ} 0' 46''$, longitude 5h. 1m. 13s.

"The watch commenced at 10h. 45m. p.m., November 13th. About eleven o'clock two or three very fine meteors were seen coming from the direction of Leo, which was yet below the horizon. At 11h. 17m. one directly from Leo. The train, of a spiral form, remained visible ten minutes near the constellation Perscus. Seventeen minutes later another in the south-west exhibited a train of similar form for the space of seven minutes. Persistency and brilliancy of train, with variety of colour, continued to be a marked feature of the whole display.

"At midnight about two hundred meteors had been counted. From this time the reckoning was as in the following Table:—

h	m	Meteors.	h	m	Meteors.	h	m	Meteors.
12	21	300	2	39	1900	4	38	3500
	34	400		47	2000		43	3700
	46	500		53	2100		47	3800
	58	600	3	9	2300		51	3900
1	17	800		18	2400		54	4000
	34	1000		31	2600		56	4100
	42	1100		45	2800	5	0	4200
	47	1200		51	2900		26	4700
	55	1300		58	3000		31	4800
2	1	1400	4	7	3100		36	4900
	9	1500		14	3200		41	5000
	23	1700		22	3300			
	31	1800		30	3400			

"The counting was discontinued at 5h. 41m., although several hundreds were seen between that time and sunrise.

"At 1h. 10m. the finest meteor of the night was seen. It appeared near the Pole-star, increasing in brilliancy as it approached Cassiopeia, and vanishing near α and β Cassiopeia with a flash of extraordinary brilliancy. The train at first had a direction nearly parallel to the line of these two stars, and about 15° in length. Immediately it commenced to spread, and soon assumed the form of an inverted S, thus $\mathcal{S}$. Then the form became that of an ellipse with a hollow ellipse at each of the two foci, all the time drifting slowly towards α Andromeda. At 1h. 55m. the train was still faintly visible at δ Andromeda, the whole time of visibility exceeding forty-five minutes.

"At about 4h. 30m., and at 4h. 31m. two meteors left trains in the vicinity of Sirius and δ , of Canis Major, each assuming the form of the Greek Ω , and continuing visible together for several minutes.

"As day began to dawn the meteors, which shot down towards and below Venus, were in many cases of a bright red or crimson colour.

"Many unconformable meteors were observed during the night, and the tracks of many of these corresponded to a radiant between the Pleiades and the Haiados.

"In several cases the remarkable phenomenon was noticed of a disappearance, and almost immediate reappearance, as of a light extinguished and re-kindled.

"In general the finest meteors were seen in the north and north-west."

The state of the weather in England on the night of the 13-14th of November was not in general favourable to observations of the shower. Yet a clear condition of the sky beginning to prevail at Glasgow at 3h. 30m. A.M., and being finally established at 4h. 30m. A.M., a perfect view of the principal portion of the display was obtained by Prof. Grant. The meteors resembled those of the 14th of November, 1866, in three or four instances leaving streaks which remained visible for two or three minutes after the disappearance of the meteor. Their colour was white, in some instances with a slight tinge of red, and the colour of the streaks was less inclined to green than in the former shower. Three or four of the meteors far exceeded Jupiter in brightness, but not equalling the planet Venus, which shone at the same time with intense brilliancy in the east. Their rate of frequency appearing to increase, their number observed in successive minutes was recorded from 4h. 56m. A.M. until 6h. 5m. A.M., when 256 meteors had been counted by one observer. The number really visible during the interval of one hour and ten minutes was in all probability three times as great as this, or as many as seven or eight hundred. The time of greatest frequency was observed at 5h. 15m. A.M., the number afterwards diminishing considerably during the continuance of the observations. In the successive intervals of ten minutes,

Ending at	..	5h.	6m.	16m.	26m.	36m.	46m.	56m.	6h.	6m.
There were	}	50	54	36	39	26	24	27	=256 meteors.	
counted										

Shortly after six o'clock, while the shower was still active, although the period of its greatest intensity seemed to have already passed, the sky became cloudy, and no further observations could be made. (Monthly Notices of the Royal Astronomical Society for December 11th, 1868, vol. xxix. p. 60*.)

At the Royal Observatory, Greenwich, the sky was densely overcast, on the

* The same Number of the 'Monthly Notices' (p. 62) contains a memorandum on the shower by Prof. D. Kirkwood, of Bloomington, Indiana, in the United States. The number counted in 6h. 31m. was 3280; one observer counting 780 in 1h. 16m., ending at 6h. 11m. A.M. The maximum was at about 5h. 30m. A.M.

morning of the 14th of November, until 1h. 57m. A.M.; it was clear from this time until 2h. 50m. A.M., and during this interval forty-six fine meteors were observed, and their apparent paths described. The number of meteors at this time was very great, both large and small, and quite bewildering; several large meteors were present at the same time, and all could not be observed. The sky then became overcast until 3h. 53m. A.M. It was clear but hazy from 4h. to 4h. 23m., when clouds began to collect increasingly until 4h. 48m. A.M., after which time the sky was overcast throughout the night. Sixty-nine fine meteors were observed, some of which were exceedingly brilliant, leaving streaks varying in duration to more than one minute. When the sky was cloudy, lightning-like flashes were frequently observed until after six o'clock, evidently connected with large meteors, lighting up the whole sky as several of the meteors were observed to do when the sky was clear. A meteor which burst, and left a streak for eight seconds midway between γ Leonis and Mars, was without motion. The majority of bright meteors observed were conformable to the radiant in Leo, other radiant-points which were discernible being generally connected with the smaller meteors.

The 'Times,' Dec. 7th, 1868, contained a letter from Dr. J. M. Hamilton, describing the meteoric shower as it appeared in Shetland. The meteors were abundant from 3h. 30m. A.M. until sunrise, sometimes appearing two or three at once, many of them brighter than Venus, and a few so bright that one could have read ordinary print, for an instant, by their light. The streaks were bright white, or in some cases of a bluish or reddish tinge; those left by some of the brightest meteors remained visible for one to three minutes, and were even visible towards daybreak. The sky was generally clear, and when it was partly overcast the meteors shone between the interstices of the clouds. The point in Leo from which the meteors appeared to emanate remained stationary among the fixed stars from 3h. 30m. A.M. until nearly the time when the sun rose.

A letter from Mr. G. T. Kingstown, Director of the Toronto Magnetic Observatory, in the 'Times' of December 8th, states that the sky was clear, except between 5h. and 6h. A.M., on the morning of the 14th of November, and that 3000 meteors were counted before that hour, 99 per cent. of the meteors radiating from the constellation Leo. Some, which exceeded Sirius in brightness, exhibited a variety of colours. The luminous streaks often continued visible from two to four minutes. The following Table shows the number of meteors seen at different parts of the night, together with the state of the sky:—

Interval in Toronto time.				Number of meteors seen.	State of the sky.
From	h	m	to		
	h		h		
From 10	12	45 P.M.	12 P.M.	173	Very clear.
"	12	0	" 1 A.M.	329	Ditto.
"	1	0 A.M.	" 2	583	Ditto.
"	2	0	" 3	489	{ Occasional very light haze.
"	3	0	" 4	375	
"	4	0	" 5	572	Ditto.
"	5	0	" 6	365	Haze increasing.
				2886	{ Clouds 0·4; very hazy.

At Rome, on the night of the 13-14th of November, 1868, the meteors began to appear about midnight, with diffuse light in the N.N.E. and N.E., several meteors being seen near the Lion's "Sickle" at 12h. 9m. From 12h. 30m. until 1h. 20m. an interval of cessation occurred, in which very few meteors appeared; but at 1h. 10m. a splendid fireball made its appearance in the Lynx (see Catalogue). From 1h. 30m. to 2h. 30m. a shower of meteors appeared in all parts of the sky, radiating from a point at the centre of the stars $\gamma, \epsilon, \mu, \zeta, \eta$ Leonis. In the N.E. and N.N.E. directions only, ninety meteors were counted in two hours. The maximum, which was also noted at the same time by Prof. Pinelli at Civita Vecchia, took place at 4h. 50m. A.M., on the 14th. The total number of meteors visible between midnight and 6h. A.M., in all parts of the sky, was probably not less than 3000. (Annuaire de l'Observatoire Royal de Bruxelles for 1868-69, p. 166; letter of Madame Scarpellini to M. Quetelet.)

The numbers of shooting-stars seen by three observers at the Observatory of the Capitol at Rome, on the night of the 13-14th of November, 1868, is thus stated by Father Secchi in a letter to Abbé Moigno, printed in 'Les Mondes' for November 26th, 1868:—

In the successive quarters of an hour ending as below, Rome time, November 14th A.M., there were seen,—

h	m	Meteors.		h	m	Meteors.
2	45	.. 29		4	30	.. 208
3	0	.. 50			45	.. 233
	15	.. 48		5	0	.. 264
	30	.. 84			15	.. 270
	45	.. 140			30	.. 339
4	0	.. 148			45	.. 250
	15	.. 141				

Total, in three hours, 2204 meteors.

According to another letter in the 'Times,' the meteoric shower was also seen with great brilliancy at Naples. A brief extract from a letter received by Sir John Herschel states that at Florence the meteoric shower was also very splendid.

At Moncalieri, and at Bra, in Piedmont, the sky was cloudless for a few hours after midnight, and the beginning of the star-shower was observed. The hourly numbers of meteors seen at Moncalieri on the nights preceding the 13th of November were:—

On the night of the	9th.	10th.	11th.	12th.	} *Sky very hazy.
Horary number of meteors.	11	*8	23	24	
	At Bra			21	
	At Alessandria			45	

As soon as the constellation Leo rose above the horizon at Moncalieri and at Bra, the meteoric shower appeared in groups of three, four, or even five meteors at once. The following Table shows the number of meteors counted at each place in the successive hours before midnight, and half-hours after midnight on the morning of the 14th of November. The sky became almost overcast at Bra at one o'clock, and completely so at Moncalieri at ten minutes after two o'clock A.M.

Intervals (p.m.) & a.m.) ending at Nov. 13-14												
	h	h	h	h	h	h	h m	h	h m	h	h m	
	7	8	9	10	11	12	12 30	1	1 30	2	2 30	
No. of Me- teors seen	Mon-											
	calieri	7	14	18	24	26	25	40	46	70	94	42*
	Bra	5	19	26	21	19	19	35	26	9*		
Total:—At Moncalieri, 406; at Bra, 179.												

The meteors seen after midnight presented the same appearance as those of November 14th, 1866, leaving brilliant streaks which often remained visible for several seconds. Their brightness exceeded that of Jupiter or Venus, of a roddish hue. Their directions were all conformable to a radiant-point in Leo, situated exactly between γ and ζ of that constellation. The gradual increase of the horary numbers shows that the maximum was not attained, and that the meteoric shower probably commenced a few hours before midnight at Moncalieri. At the neighbouring station of Mondovi, where the sky was partially clear from 4h. until 4h. 15m. a.m., eighteen bright meteors were counted in the few clear spaces; and after this time, when the sky was completely overcast, two meteors and fifteen lightning-like flashes were seen through the clouds by Prof. Bruno, in the space of a quarter of an hour, between 5h. 30m. and 5h. 45m. a.m.

On the night of the 14th-15th, observations of meteors in Piedmont were prevented by bad weather at all the stations. (Letter from Father F. Denza to the Secretary of the Committee.)

At the Royal Observatory of Madrid the horary number of meteors did not surpass six or eight on the night of the 12th-13th, and before midnight on the night of the 13th. From that time until 2h. a.m. on the 14th 200 meteors were counted by two observers, among which six or seven bolides illuminated the country round the observatory with the brilliancy of moonlight. The radiant-point of all the meteors was in Leo. Between 2h. and 3h. a.m. the number of meteors seen by the two observers rose to 350 in one hour. A splendid fireball (see Catalogue) appeared at 2h. 33m. a.m. Between 3h. and 4h. a.m. the number of meteors seen remained about the same as in the previous hour, after which time they became more frequent; and between 5h. and 5h. 30m. a.m. twenty meteors could be counted in a minute. One meteor in every ten was then brighter than a first-magnitude star; their course was short, especially near the radiant-point, which was close to η Leonis. After 5h. 30m. a.m. the intensity of the shower began to decline, the approaching dawn at the same time obscuring some of the smallest meteors.

The majority of the nuclei were bluish, many white, a few bright red, and a very few bright emerald-green. The maximum probably occurred soon after daybreak, as thirteen bright meteors were counted between 6h. and 6h. 35m. a.m., when Mars, Sirius, and even Venus had disappeared, and the last meteor observed was recorded five minutes before the sun rose.

During the night of the 14th-15th, as on that of the 12-13th, the number of meteors was very small. A large fireball must, however, have appeared at 12h. 20m. a.m. (see Catalogue), as its bright persistent streak remained visible for several minutes.

The appearance of the maximum of the shower in 1868 was accordingly chiefly visible in America, and the first commencement of the shower was not discernible in Europe. Although less dense in its frequency, yet in the greater extent of its duration, and uniformity of its structure, the meteoric

* During these half-hours the sky was partly overcast.

cloud in 1868 considerably surpassed that traversed by the earth on the 13th–14th of November, 1866.

3. *Meteoric Shower of December 12th, 1868.*—The cloudy and unsettled state of the weather in England on the periodical night of the annual return of this meteor-shower prevented any continuous observations of shooting-stars. A considerable shower of meteors was, nevertheless, noted by Mr. Wood, at Birmingham, who reports as follows:—

“Some meteors were observed on the 10th, but the overcast state of the skies on the nights of the 11th, 12th, and 13th prevented observations requisite to fix the time and intensity of the maximum (except within wide limits). An hour’s observation, however, on the morning of the 12th gave evidence of a good display, namely, twenty meteors per hour for one observer, of which 53 per cent. radiated very accurately from θ Geminorum, and the remaining 47 per cent. from the coexistent radiant, Ga, LG, R_g, RG. The shower presented the usual features,—meteors white, with an occasional bluish tint, brief in duration and trainless.”

4. *Meteoric Showers of January 2nd, April 11th and April, 20th, 1869.*—At London and Manchester the sky on the night of the 2nd of January was densely overcast. On the night of the 3rd the sky was remarkably clear in the neighbourhood of London. Mr. Crumplen, and two other observers, watching there, independently, for several hours failed, however, to get a glimpse of any shooting-stars. If the shower took place on the previous night it must accordingly have been short-lived, and its limits must have been defined within very narrow bounds. Mr. Crumplen also watched for meteors on the night of the 24th of December, 1868, when the sky was partially clear, without success. The unfavourable character of the weather for observations of luminous meteors in England throughout the last winter and early part of the spring was equally attended by negative results on the 10–11th, and 20th of April, 1869.

At Moncalieri, in Piedmont, forty meteors were observed on the evening of the 11th of April, of which two were bolides (see Catalogue) whose apparent paths were accurately recorded. Two other bolides appeared on the same evening with such brilliancy that the attention of all the seven observers stationed on the terrace of the observatory, and looking towards different parts of the sky, was drawn towards them by their light. Father Denza is preparing for publication the observations of meteors made in Piedmont during the first four months of the present year, among which the number of bolides recorded has been unusually large.

On the morning of the 21st of April, 1869, between 2h. and 4h. A.M., eighty-four meteors were counted at Moncalieri, of the usual characteristic brightness, and radiating, with the general uniformity of the meteors of this shower, from a point in the neighbourhood of the constellation Lyra. (Bulletins of the Royal Academy of Belgium for June 1869, vol. xxvii. p. 632–4.)

In the Meteorological Bulletin of the Observatory of Urbino for April and May, 1869, Prof. A. Serpieri records the apparent paths of forty-one shooting-stars, observed during the evenings of those months; nine of which were observed in 1h. 10m. on the morning of the 21st of April. The last of these nine April meteors was of red colour, moved slowly, as if resisted in its flight, and left sparks of light upon its track. In a reply to Prof. Serpieri, who sent these observations to him at Milan, Prof. Schiaparelli writes:—“Seven of the nine meteor-tracks proceed from a radiant-point at about R.A.=267°, N. Decl.=+35°. The radiant-point of the Comet I., 1861, is at about R. A.=270°·4, N. Decl.=+33°·5.

“The positions of the radiant of this meteor-shower, as stated by other authors, are as follows:—

Greg.....	R. A. 282 ⁰	N. Decl. +33 ⁰
A. Herschel.....	277.5	+34.5
Heis	277	+38
Galle and Karlinski....	278	+34.5

“Your observations, accordingly, are more nearly conformable to the radiant-point of the comet than those of all the other observers.”

Eight meteors observed in one hour, on the evening of the 1st of May, diverged from a radiant-point which remained sensibly fixed at about R. A. 202°, N. Decl. 62°. The position of the radiant-point M 7, 8, near η Ursæ Majoris, as given by Mr. Greg in the last edition of the ‘British Association Atlas’ (see Report for 1868, p. 401), for the interval between April 25th and May 25th, is at R. A. 202°, N. Decl. 52°, about 10° from the position assigned to the vanishing-point of these meteors at Urbino.

5. *The August Meteor-shower in 1869.*—The following Table contains a summary of observations by Mr. Greg, at Manchester, on the periodic nights of the 9–11th of August. During the intervals of time recorded in the list, the sky was generally clear.

Date and interval of observations.				Average rate of frequency of the meteors seen by one observer.		Remarks and average radiant-point.
1869.	h	m	h	m	m	
Aug. 9.	10	5	11	25	1 in 5 or 6	Radiant about B Camelopardi.
	11.	12	5	1 25	1 2½	Mostly Perseids; radiant ½ Persei.
	12.	10	15	11 45	1 4	One half appeared in 20m., between 10h. 15m. and 10h. 35m. A.M.

Mr. Greg observed a fireball, three times as bright as Jupiter, on the evening of the 9th, at 10h. 23m. P.M. It was bluish white, and lasted one second, commencing at γ Pegasi, and proceeding 12° or 15° in a direct course from η Persei. The meteors on the night of the 10–11th were bluish white, of short course, and leaving momentary streaks in those of first and second magnitude, and dull yellowish-red in the smaller stars; they radiated from near η , $\frac{1}{2}$ Persei, instead of from Cassiopeia as during the previous years, or from B Camelopardi as on the preceding night, and were about twice and a half as frequent as on the evening of the 9th, coming occasionally in groups of two or three in a minute, after a lull of five or six minutes without any appearance of a shooting-star. No large meteors were seen on the nights of the 10th and 11th.

At Broadstairs, in Kent, Mr. George Chapman noted the appearance of eight meteors, about the average brightness of second-magnitude stars, two of which left momentary trains, during the half-hour from 9h. to 9h. 30m. P.M. on the evening of the 10th, and two similar shooting-stars during the quarter of an hour ending at 10h. 15m. P.M. on the evening of the 12th of August. The duration and length of path of these meteors was about 10° in less than two seconds. Their colour was principally white, and the apparent paths of all were remarkable for the uniformity with which they radiated from a point about midway between γ Persei and the bright stars of Cassiopeia. On the night of the 11th the sky was overcast.

The particulars of the observations of the meteoric shower at Birmingham are summed up by Mr. W. H. Wood in the following remarks:—

Date and interval of observation.	Numbers of meteors seen.	Condition of the sky.
1869.		
Aug. 8. At night .....	.....	Quite overcast.
" 9. 10 ^h 30 ^m P.M. to 11 ^h 30 ^m P.M.	16	Quite clear.
" 10. At night	1	Overcast (occasional clear spaces).
" 11. 10 ^h to 11 ^h P.M.	4	Clear.
" 11. 11 ^h to 12 ^h P.M.	12	Clear.
" 12. At night .....	.....	Overcast.

Active radiant points observed.	Number of meteors ob- served, per cent., from each radiant.	Magnitudes as per stars.	Number of meteors per cent.
η Persei	30	Equal to or brighter than	
γ Persei	16	1st-magnitude star	30
ϵ Cassiopeiæ	16	2nd-magnitude star	25
T, T ₂ , 3, 4 (in Pegasus)	10	3rd ditto, and under	45
N st , 1, R, (χ , κ , α Persei), and other radiant-points	28		
	100		100

"Colours of the meteors bluish white, yellowish white, pale green. The present display exhibits a decline below the average of the past ten years in hourly numbers and apparent magnitudes, which differ strikingly from the corresponding data of the August meteor-shower in 1868 (see the Report for that year, p. 381). The proportion of small meteors will be found to have increased twofold, and of the more conspicuous ones to have diminished in the ratio of about 3 : 5. A curious feature is presented by the fact that the percentage number of meteors diverging from η Persei in the present year is the same as that of the meteors radiating from the same centre in the year 1868, and that the percentage numbers of meteors from γ Persei and ϵ Cassiopeiæ are, as in that year, equal to each other, and only less by four than in the year 1868. The frequency of meteors from the radiant-points in Pegasus is this year a little in excess. The data furnished by this year's observations regarding the other coexisting radiant-points are insufficient for comparison with those of former years. There were no sporadic meteors."

Up till the 8th of August the number of meteors observed during the month, in Piedmont, exceeded 1500, of which Mr. Denza will publish a description and chart in the 'Bulletino' of the Observatory of Moncalieri. At Moncalieri itself the following numbers of meteors were observed on the nights of August

1st.	2nd.	3rd.	4th.	5th.	6th.	7th.
15*	72	87	69	overcast	39†	17*

The sequel of the remaining observations of the August period at Moncalieri, and at other places in Italy, will be published in the Monthly Bulletin of that Observatory. Many of the meteors radiated from Cygnus, and from Cassiopeiæ. (Letter of F. Denza to Mr. R. P. Greg.)

* Overcast.

† Partly overcast.

A letter from M. Amadée Guillemin to the Secretary of the Committee, describes the state of the sky, at Paris, on the night of the 10th of August as overcast, and, accordingly, unfavourable for observations of the August meteoric shower.

General Radiant-points of Shooting-stars.—Copious lists of shooting-stars observed in Piedmont and Italy during the last two years have been communicated by their authors to the Committee, whose object it has been to reduce them, for comparison with the results obtained from the British Association Catalogue, whenever a constant divergence appeared to present itself among the meteors, to specific radiant-points. In this inquiry their labours have met with encouraging success by the complete verification of a considerable number of the known radiant-points, and by the means of rectifying the positions and durations of others, less certainly established by the paucity of previous data, afforded by the additional observations.

Mr. R. P. Greg having lately projected on the Celestial Maps, in use by the Committee of the British Association, about 150 meteor-tracks, from observations made last year under the care of Signor Denza, Director of the Observatory at Moncalieri in Piedmont, and since published in the Meteorological Bulletin of that Institution, has been enabled to redetect and verify the radiants AG_1 , M_1 , M_2 , MG , $A_{1,2}$; and more slightly the radiants $A_{3,4}$, SG_1 , $S_{2,3}$, NG , $M_{4,5}$. The observations in question were made on the evenings of the 7th–19th January; and 30th January to 6th February, 1868. Two new radiants were also fairly obtained, not before noticed by Greg and Herschel,—one for the evenings between the 29th of January and (?) 6th of February, near Quadrans, R. A. = 223° , N. Decl. 54° ; and the other near μ Eridani, R. A. = 73° , S. Decl. 2° , for the evenings of the 9th–19th January, and at γ Orionis, R. A. = 68° , N. Decl. 6° , for 30th January to 5th (?) 11th of February.

The former of these, at Quadrans, is evidently identical with Heis, K_2 , at R. A. 227° , N. Decl. 60° , for 15th–31st January, but must certainly not be identical with the special shower, $K_{1,3}$, of Greg and Herschel for January 2nd, which, there is good reason to believe, is a shower of only twenty-four hours' duration.

Mr. Greg also finds in Signor Zezioli's observations, made at Bergamo, April 25th–May 3rd, 1868, abundant confirmation of the radiants W , WG , Q_1 , DG_2 ; also of N_2 , OZ , and OZ_1 .

Prof. Serpieri, in the 'Bulletino Meteorologico' of Urbino for August 1868, gives a radiant for eight shooting-stars on the 11th of July, 1868, the position R. A. 200° , N. P. D. 35° , which almost exactly agrees with the radiant MG_1 for July 1st–11th, as determined last year by Mr. Greg (Report for 1868, p. 403) from Signor Zezioli's observations, made at the same time at Bergamo, the position determined being at R. A. 210° , N. P. D. 35° , as given in the 2nd edition of the 'Celestial Atlas,' published last year by the British Association.

Considerations of the space usually allotted in these Reports to observations of luminous meteors (which in the present year is amply occupied), and a sense of the scientific importance of the papers communicated, during the past year, by their authors to the Committee, will only permit a list of their titles and of the principal contents of their pages to be here appended. The annually decreasing splendour of the November meteor-shower, and the absence of its attendant observations, will, in a future year, enable the recent contributions of special importance to meteoric literature to be carefully reviewed.

1. "Le Stelle Cadenti del Periodo di Agosto osservate in Piemonte ed in

altre contrade d'Italia nel 1868" (Fourth Memoir on Shooting-stars observed in Piedmont and Italy, by Francesco Denza, Director of the Observatory of the Royal University of Moncalieri, near Turin).—Several extracts and references to the memoirs have been made in former Reports, and principally to the present memoir in this Report (Appendix III.) on the August meteoric shower in 1868.

2. "Le Meteore Cosmiche," Milano, E. Treves & Co., Biblioteca utile, 1869, by the same author, is a brief but lucid lecture, delivered to a popular audience at the Museum of Natural History and Philosophy in Florence, on the subject of the recent discoveries in cometic and meteoric astronomy.—The author, in common with Schiaparelli, regards comets, aërolites, and shooting-stars as bodies of a common origin in the nebulous matter of the universe, differing only from each other in the degree of concentration wrought in them by the effects of universal gravitation and of time. The gaseous and self-luminous character of the nucleus of Tempel's comet, observed by Huggins, which is not referred to by Father Denza, differing so essentially from that of aërolites, does not receive any very obvious or satisfactory explanation on this hypothesis.

3. "Études géométriques sur les Etoiles filantes," par G. M. Goulier (in 8vo, pp. 154, with plates: Metz, F. Blanc, 1868).—The principal object of the work is an instructive manual intended to direct the observations of shooting-stars projected by the recently instituted Meteor-Committee of the Imperial Academy of Metz. The phenomena of visibility, rate of apparition, apparent position, and hourly variation of the radiant-point, and the calculations of the real heights, velocities, and dates of the periodical returns of shower-meteors are discussed, with mathematical formulæ intended to adapt the careful observations of luminous meteors conveniently and with increased accuracy to the development of the new cosmical theory of shooting-stars. The same clear arrangement and demonstrations of all the fundamental propositions of Professors Newton and Schiaparelli on the apparitions of shower-meteors and their orbits are given in subsequent chapters of the work. The sixth and last chapter contains a review of the conjectures to which the cosmical theory of luminous meteors has given rise, and suggests some brief considerations on the possible identity of shooting-stars and aërolites.

4. "Zur Theorie der Sternschnuppen," von A. Erman (extracted from Erman's 'Archives,' vol. xxv. part 3: Berlin, 1867).—A detailed account of the attempts is given, which were made before the time of Schiaparelli, to determine the form and dimensions of the August and November meteor-orbits,—first, on the method employed by Erman, and adopted by other observers of determining by direct observations the real velocities of the meteors, relative to the earth; and, secondly, in the manner adopted by Professor Newton, of determining the periodic time of revolution by examining the dates of ancient star-shower records. The description of the first of these two methods, adopted by astronomers from the time of Benzenberg and Brandes, occupies the principal and most extensive portion of the narrative. The third, and last method, which led Schiaparelli to discover the quasi-cometary character of the meteor-orbits by calculating the velocities of shooting-stars from the laws of their annual and diurnal variations of frequency, receives full exposition in the last few pages of the pamphlet.

5. "Expériences synthétiques relatives aux Météorites. Rapprochements auxquelles ces expériences conduisent," par M. A. Daubrée (in 8vo, pp. 68: Dunod, Paris, 1868).—The experiments of fusion and crystallization of meteorites and terrestrial rocks, and on the imitation of aërolites by the

reduction and oxidation of various minerals (see Report for 1868, p. 415), led M. Daubrée to the conclusion that the latter process of *imperfect* scorification, like that which the materials of the earth's crust appear to have *completely* undergone by oxidation, represents the original process of formation of meteorites. In the rare aluminiferous meteorites of Juvenas, Jonzac, Stannern, and Petersburg (U. S.), the crystallization, like that of granite on the earth, can only have taken place in the presence of water; since their felspathic ingredients are converted into glass or vitreous slags by fusion. Some new points of interest on the classification of meteorites *, and on the recent acquisitions in the Paris Museum of Geology of aërolitic specimens, are added by M. Daubrée to the former chapters of his original researches, which are otherwise reproduced in the present pamphlet without change. Among the recent specimens acquired at Paris, not less than 950 perfect aërolites of the stonefall of Pultusk (1868, January 30th), varying from the size of a hazel-nut to that of a hen's egg, have lately been deposited by M. Daubrée in the Geological Museum.

6. In 'Cosmos' for January 18th, 1868, M. Stanislas Meunier communicates a new chemical test for distinguishing the protosulphuret of iron (FeS) from the ordinary terrestrial magnetic sulphuret or pyrrhotine (Fe_7S_8). The former, even when slightly supersulphuretted, precipitates metallic copper from its solutions; but when the proportion of sulphur approaches to that contained in pyrrhotine, and in the case of the mineral pyrrhotine itself, no such precipitate is produced. The fact that the magnetic sulphuret of iron (troilite) found in meteorites remains inactive, or "passive," when placed in a solution of sulphate of copper, leads M. Meunier to conclude that its chemical formula and mineralogical characters approach more nearly to those of pyrrhotine (Fe_7S_8) than to those (with which it is usually compared) of the protosulphuret of iron, FeS . A paper by the same author, in the 'Cosmos' for March 21st, 1868, describes at length the process employed in the laboratory of the Paris Museum of Geology for analyzing meteoric irons.

7. "Licht, Wärme, und Schall bei Meteoritenfällen," von W. v. Haidinger (extracted from the Vienna Academy Sitzungsbericht, vol. lviii. part 2, for October 8th, 1868).—An English version of the paper appears in the Philosophical Magazine for April, 1869.

Some remarks by M. Daubrée and M. Meunier in the foregoing papers appearing to admit of theoretical exceptions, the opportunity of reviewing the facts recently observed regarding the falls of the meteorites in different parts of the globe, and the conclusions to which they lead in confirmation of M. Haidinger's views of their interpretation, is made the occasion of a clear exposition by the eminent mineralogist of Vienna of the progress of aërolitic science during the long time in which it has engaged his attention, and especially of the rapid strides which, owing to the able geological and astronomical inquiries which have recently been devoted to the subject, it has principally been enabled to make during the last few years.

8. "Recherches sur la composition et la structure des Météorites," par M. Stanislas Meunier (in 4to, pp. 73: Gauthier Villars, Paris, 1869).—A thesis presented to the Faculty of Sciences of Paris for the award to the author of the degree of Doctor in Physical Science).—The results of special methods of analysis employed in foreign, and original researches on the composition of a large number of meteoric irons are recapitulated by M. Meunier at the end of the memoir, in the following general conclusions:—

* 'Comptes Rendus' for March 25 and April 2, 1867, and subsequent Numbers.

1°. Meteoric irons consist of a small number, only, of different minerals combined together in variable proportions.

2°. These minerals, which may be called *proximate ingredients of meteoric irons*, possess physical and chemical characters which enable them to be separated from each other in a state of purity.

3°. The majority possess a definite composition, capable of being expressed in simple chemical formulæ.

4°. They are not mixed together at random in the masses which they compose, but their positions relatively to each other obey certain fixed laws.

5°. Lastly, proximate chemical analysis of meteoric irons affords the only effectual means of obtaining a satisfactory classification of these bodies.

9. Observations on the recent November meteoric showers.

"Shooting-stars on the morning of November 14th, 1867," by H. A. Newton (American Journal of Science for January 1868, vol. xlv. p. 78), contains a discussion of the principal observations of frequency of the meteors, and a curve showing the time of maximum of the star-shower, as observed in the United States, together with some remarks on its geographical extent of visibility, on the probable width of the stream, and its possible connexion with the comet observed in China on the 25th of October, A.D. 1366.

"On the 'Shooting-stars' [of November 1867] as observed at Shanghai," by B. V. Marsh (Proceedings of the American Philosophical Society, vol. x. p. 384).—The following notes of a meteor-shower which occurred in China on the 15th of November, 1867, were received by Mr. Marsh from Mr. B. R. Lewis, U. S. Deputy Consul-General at Shanghai.

Log of U. S. steamer 'Ashuelot,' Capt. Febiger, at Shanghai:—"Nov. 15th, 1867, 4^h to 8^h A.M. Large number of shooting-stars to the N. and E. falling to the N.; visible until broad daylight. Clear and cold; light N.W. winds."

Log of U. S. steamer 'Monocacy,' Capt. Carter, at Shanghai:—"November 15th, 1867, from midnight to 4^h A.M. At 2^h A.M. observed a number of meteors falling from the westward towards the east. This shower of meteors continued till 4^h A.M., decreasing in number from 3^h, seven or eight being the largest number visible at one time.

"From 4^h to 8^h A.M. Between 4^h and 5^h observed several meteors falling to the eastward."

Extract from the 'Shanghai News Letter' of January 16th, 1868 [*].—"From Mr. O. B. Bradford of the U. S. Consular Service we obtain the following glowing account of the meteoric shower of 1867, as witnessed by him not far from the great wall of China. It was on the morning of the 15th of November, while on his way back from the Nankow Pass, and when about fifty miles N.N.W. of Pekin, that Mr. Bradford observed these grand phenomena of the heavens. The grand spectacle was displayed in an arc of not less than 120° in the north-east part of the sky, which at times seemed to be rent in twain, from about 25° of the zenith, by solid masses of luminous bodies, of various magnitudes and surprising brilliancy, darting across his vision. Several hundreds [!] of these meteors would be visible at the same time, all emitting the most intense light, and the nebulae of the largest lasting sometimes three minutes. One of the largest shone with brightness above that of the moon as it issued from about 15° of the north star and passed to the horizon, giving off as it fell coruscations of various bright colours, and,

[* The paragraph is considerably curtailed from the figurative language and descriptions of the original article.]

when disappearing, a nebula, which resembled a waterspout in high latitudes. It was not until 6^h 30^m A.M. that approaching dawn and sunrise put an end to the display."

In reference to these accounts, it is stated by Mr. Marsh that the observations of 1866 afforded no ground for expecting this Asiatic display of 1867, since the star-shower appeared and disappeared in the United States of America within two hours of its appointed time, or at about 4^h 30^m A.M., New York time, on the 14th of November. Since the latter hour would, from the difference of longitude (12^h 40^m east of New York), and from the commencement of the day earlier (by that space of time) in China than in America, correspond to about 5^h 10^m P.M. on the afternoon of the 14th of November at Shanghai, it follows that the Chinese shower of November 15th, 1867, was observed *ten or twelve hours later*, in absolute time, than the time of the great appearance of the November meteors in the United States. On the other hand, it has since been pointed out by Mr. Marsh, in a more recent communication to the Committee, that the maximum of the great November star-shower of 1865 was visible in America, and in Europe, on the morning of the 13th of November, about *twelve hours earlier* than corresponded to the time of the principal apparition of the shower in the years 1866 and 1867. The central and densest portion of the meteor-stream through which the earth passed in the latter years appears accordingly to be flanked on either side by lateral and somewhat less dense but wider meteoric currents at a distance from the orbit of the main stream, which the earth crossed in about twelve hours on the mornings of the 13th of November, 1865, and 15th of November, 1867. The Asiatic shower of the latter date accords *almost exactly* in its epoch with the unexpected reappearance last year in Europe and America of the great display of meteors on the morning of the 14th of November 1868.

The following extract of a letter from Mr. Marsh to the Secretary of the Committee, dated Philadelphia, January 15th, 1869, contains an ingenious and clear statement of the above interesting result derived from the recent observations :—

"The Chinese maximum was at about 3^h 30^m P.M. November 14th, Philadelphia time, so that we should have been in the centre of that group, or stream, *this year* at 9^h 30^m P.M. November 13th. The shower which we actually encountered was in full progress here by 11^h 30^m P.M., and from the European observations it is proved to have begun two hours earlier. Whereas the *American shower* of 1867 should have begun at 9^h A.M. November 13th, and ended at about noon on that day, our shower of this year seems much more directly to represent the *Chinese* than the American shower of 1867.

"We had, on the 13th of November, 1865 (maximum at about 3^h A.M.), quite a fine display, much exceeding (I judge from your Reports) yours of the same year, so that the principal displays of the present series were as follows :—

Place, year, and local time of maximum.		Philadelphia time of do.	
" Shower A.	Philadelphia, 1865, Nov. 13, 3 ^h 0 ^m A.M. ...	1865, Nov. 13, 3 ^h 0 ^m A.M.	
" B.	London, 1866, " 14, 1 15 " ...	1866, " 13, 3 0 P.M.	
" C.	Philadelphia, 1867, " 14, 4 30 " ...	1867, " 14, 4 30 A.M.	
" D.	Shanghai, 1867, " 15, 4 30 " ...	1867, " 14, 3 30 P.M.	
" E.	Philadelphia, 1868, " 14, 3 0 " ...	1868, " 14, 3 0 A.M.	

"Philadelphia should have crossed those several streams, *this year*, as follows :—

"Meteoric stream, and its duration.				Time of maximum.			
A.	1868,	Nov. 12,	7 ^h 0 ^m P.M. to 9 ^h 0 ^m P.M.	.....	1868,	Nov. 12,	9 ^h 0 ^m P.M.
B.	"	"	13, 7 0 A.M. to 9 0 A.M.	.....	"	"	13, 8 0 A.M.
C.	"	"	13, 9 0 A.M. to 12 0 (noon)	.....	"	"	13, 10 30 A.M.
D.	"	"	13, 7 30 P.M. to 11 30 P.M.	.....	"	"	13, 9 30 P.M.
E.	"	"	13, 10 0 P.M. to 8 0 A.M. (Nov. 14)	.....	"	"	14, 3 0 A.M. [*]

The accompanying diagram, subjoined to the last Table by Mr. Marsh, most clearly illustrates its meaning, and the relation which the several November meteor-streams recently observed bear to each other when reduced to a common epoch:—

	6h. 1868, Mid- P.M. Nov. night.	13th.	6h. A.M.	12h. Noon.	6h. P.M.	Mid- night.	14th.	6h. A.M.	Noon.
Meteoric stream	A. <u>America</u> 1865								
B.			<u>Europe</u> 1866						
C.				<u>America</u> 1867					
D.					<u>Asia</u> 1867				
E.								<u>America, 1868</u>	

"November Meteors of 1868, observed at the U. S. Naval Observatory, Washington" (Report of Professor J. R. Eastman, with a chart of the meteor-tracks).—For the purpose of determining with accuracy the position of the radiant-point, and to afford means for calculating the real altitudes and velocities of the November meteors, gnomonic charts of the heavens, having the constellation Leo in the centre of the map, were last year distributed by the Meteor-committee of the Newhaven Academy. The tracks of 90 meteors were recorded on such a chart, which accompanies the Washington Report; and by its means the position of the radiant-point was fixed at a well-defined point in R. A. 148° 30', N. Decl. 22° 30'. The points of beginning and end of these apparent tracks are given, in a table, by their right ascensions and declinations. The maximum frequency occurred at about 5^h 0^m, when they fell at the rate of about 2500 per hour, and by 6^h A.M. 5078 meteors had been counted. The display continued until after daybreak, and was the grandest ever witnessed at the Washington Observatory. The majority of the meteors, although obscured by the full moonlight, surpassed in brightness those of the previous year. The trains of two large fireballs, after passing through colours of red, green, and blue, at last formed light fleecy clouds, and remained visible, respectively, for ten, and thirty minutes.

"Meteors of November 14th, 1868," by H. A. Newton (American Journal of Science and Arts, vol. xlvii. p. 399, with two plates).—Especially provisions were made by the Newhaven Luminous-Meteor Committee, in November last, to obtain carefully recorded observations of the apparent paths of meteors, at the return of the expected star-shower. Among the shooting-stars whose positions were thus mapped, or sufficiently described, accounts are given in the memoir of ten large meteors; and of this number, five were observed at distant places, so that the real altitudes of the meteors, or of their luminous streaks, could be determined. The largest fireball was observed at 1^h 12^m A.M., N. Y. T., the streak of which remained visible for forty minutes over the south-eastern part of Pennsylvania, between Newhaven and Washington, at both of which places its apparent place was noted. Par-

[* Time of the shower as actually seen in 1868.]

ticulars of this brilliant fireball and of the remaining large meteors, whose real altitudes were ascertained, are described in Appendix I. of this Report.

10. "Das November-phänomen der Sternschnuppen in seinen einzelnen Erscheinungen von den ältesten Zeiten bis 1866," von G. von Boguslawski, in Stettin (no date or reference).—The catalogue is completed until the 12th 14th of November, 1849, and its continuation is reserved for a future publication.

11. "On Shower Meteors," by Dr. Edmund Weiss (Astronomische Nachrichten, No. 1710).—On the supposition that comets must, in general, be accompanied by meteoric clouds, Dr. Weiss has computed the following data regarding the comets whose orbits nearly intersect the orbit of the earth, either at their ascending (ϖ) or descending nodes (ϖ). The following Table gives the longitude and date of passage of the earth through the comet's node, the difference (at that point) of the sun's distance from the earth (R), and from the comet's orbit (r), the apparent position of the radiant-point of the cometary particles, and (the tabular logarithm of) their velocity, relative to the earth.

The distance ($R-r$) of the earth (at node) from the comet's orbit in the direction of the sun is expressed in terms of the earth's distance from the sun as unity.

No.	Comet.	Longitude.	Date.	$R-r$.	Radiant-point.		Log. of geocentric velocity.
					R. A.	N. Decl.	
1.	1792 II. ϖ	284.1	Jan. 5.	-0.066	193.8	+24.6	0.3447
2.	1840 I. ϖ	300.1	20.	+0.036	128.4	-28.6	0.1112
3.	1718 ϖ	309.8	29.	-0.042	208.4	-31.2	0.3714
4.	1857 I. ϖ	313.1	Feb. 2.	-0.028	261.3	+23.2	0.2352
5.	1092 ϖ	316.1	5.	-0.012	103.2	-34.4	9.8977
6.	1854 IV. ϖ	324.4	13.	+0.015	304.0	+37.3	0.0132
7.	1858 IV. ϖ	324.9	13.	+0.045	271.8	+11.8	0.2661
8.	1862 IV. ϖ	355.6	Mar. 16.	+0.013	249.4	+1.0	0.3467
9.	1683 ϖ	355.6	16.	-0.052	206.9	-48.4	0.2574
10.	1763 ϖ	357.6	18.	-0.026	312.4	+21.6	0.1884
11.	1861 I. ϖ	29.8	Apr. 20.	+0.002	270.4	+33.5	0.2001
12.	1790 III. ϖ	34.0	24.	-0.063	319.1	+19.0	0.3020
13.	1863 II. ϖ	71.1	June 2.	-0.054	0.5	-44.7	0.3015
14.	1684 ϖ	90.6	22.	-0.010	62.7	-47.1	0.1323
15.	1850 I. ϖ	92.9	24.	-0.065	312.4	+60.6	0.1405
16.	1864 II. ϖ	95.0	27.	+0.047	12.0	+6.3	0.3742
17.	1737 II. ϖ	125.5	July 29.	+0.025	175.2	+70.9	9.9872
18.	1852 II. ϖ	137.5	Aug. 10.	-0.013	40.7	-13.4	0.3336
19.	1862 II. ϖ	146.4	19.	-0.027	47.5	+13.0	0.3750
20.	1854 III. ϖ	167.6	Sept. 10.	-0.018	53.0	-15.8	0.2819
21.	1790 I. ϖ	173.7	16.	-0.053	108.1	+37.7	0.3519
22.	1763 ϖ	177.6	20.	+0.029	44.5	-24.1	0.1856
23.	1864 IV. ϖ	203.0	Oct. 16.	-0.044	209.6	+42.7	0.0778
24.	1779 ϖ	206.0	19.	+0.022	39.3	-29.7	9.9863
25.	1849 I. ϖ	215.2	29.	-0.027	185.0	+61.1	0.2236
26.	Biela ϖ	245.8	Nov. 28.	+0.011	23.4	+43.0	9.7282
27.	1819 IV. ϖ	257.6	Dec. 9.	+0.086	346.2	-44.5	9.5504
28.	1680 ϖ	274.5	26.	+0.050	132.0	+21.4	0.2347

The comet No. 21 agrees too closely in all its particulars with the course of the meteors of the 20th of April, from an observed radiant-point about in R. A. $278^{\circ}7$, N. Decl. 35° , to leave any doubt of its connexion with the star-shower of that date. Dr. Oppolzer, who observed the comet, remarks that the visible connexion between its tail and nucleus was so slight as to appear as if it would shortly be dissolved; and the possibility that the comet is gradually becoming broken up into portions is not an improbable assumption to account for the extremely irregular returns of this great meteoric shower. The occurrence of a meteoric shower with a radiant-point in Cerberus (R. A. $273^{\circ}0$, N. Decl. $25^{\circ}5$), observed by Professor Herschel on the morning of the 13th of April, 1864, agrees well with the elements of the same comet as computed by Oppolzer.

	Orbits of the Meteoric Streams of		Orbit of Comet I., 1861. Oppolzer.
	April 13th and	April 20th.	
$\varnothing$	23°	30°	$29^{\circ}8$
π	235°	229°	$243^{\circ}2$
i	95°	83°	$79^{\circ}8$
$\log q$	9.9706	9.9907	9.96412
e	1.0	1.0	0.98346

Again, reducing the nodal passages of Biela's comet at former returns to the fixed equinox for 1850.0, they are found to be, with the corresponding positions of the radiant-point:—

Year.	Long. of $\varnothing$	Nodal passage of the Earth.	Position of the Radiant.	
			R. A.	N. Decl.
1772	$258^{\circ}4$	Dec. 10	$18^{\circ}7$	$58^{\circ}1$
1826	$251^{\circ}8$	„ 4	$22^{\circ}8$	$47^{\circ}7$
1852	$245^{\circ}8$	Nov. 28	$23^{\circ}4$	$43^{\circ}0$

The meteors observed on the 6th–8th of December by Brandes in 1798, by Flangergues and Herrick in 1838, and by Heis in 1847, are stated by the latter observer (*Die Periodischen Sternschnuppen*: Cöln, 1849) to have radiated from a point in Cassiopeia at about R. A. 25° , N. Decl. $+40^{\circ}$. In his latest list of radiant-points the radiant A_{10} for the first half of December is placed at R. A. 21° , N. Decl. $+54^{\circ}$, while in Greg's list of radiant-points (see Report for 1868, p. 403) the elongated radiant $A_{11, 10}$, producing meteors in November and for some weeks earlier, is situated between α and δ Cassiopeia from R. A. 10° to 25° , and N. Decl. 54° to 60° . The radiant is supposed to be continuous with A_{10} (Nov. 23–Dec. 18), near B Camelopardi, whose position is about at R. A. 45° , N. Decl. 60° . Observations on shooting-stars on the nights of the last week of November and first week of December accordingly deserve particular attention, with a view to determining the exact position of their point of radiation.

The following are some other comets of the list, all the particulars of whose nodal passages and radiant-point appear to agree approximately with those of meteoric showers included in Greg's catalogue of radiant-points for the northern, and Heis and Neumayer's catalogue for the southern hemisphere. The particulars of the meteor-showers apparently indicated are placed for comparison, in the Table, adjoining those computed from the cometary orbits to which they appear to correspond:—

In the Northern Hemisphere.

No.	Comet.	Date.	Radiant.		Grog's letter.	Radiant.		Epoch.	Place by Stars.
			R. A.	N. Decl.		R. A.	N. Decl.		
1	1792 II. 8	Jan. 5 ...	193.8	+24.6	MG ₁	187-172	+40 to +36	Jan. 1 25	Canes Venatici
(?) 6	1854 IV. 8	Feb. 13	304.0	+37.3	WZ	305	+37	Mar. 15-Apr. 20	γ Cygni.
8	1862 IV. 8	March 16	249.4	+ 1.0	SZ	247	- 3	Mar. 3 25	δ, ε Ophiuchi.
15	1850 I. 8	June 24	312.4	+60.6	B ₁	325	+60	June 11-July 11	α Cephei.
17	1737 II. 8	July 29	175.2	+70.9	V	172	+60	July 29-Sept. 6	α, δ Ursæ Majoris.

In the Southern Hemisphere.

									No. of meteors mapped.
2	1840 I. 8	Jan. 20	128.4	-28.6	Γ ₃	105	-27	January	30
5	1092 8	Feb. 5 ...	103.2	-34.4	Γ ₃	105	-45	February	15
9	1683 8	March 16	206.9	-48.4	11 ₁	192	-38	March	15
24	1779 8	Oct. 19...	39.2	-29.7	X ₁	10	-35	October	12

Meteoric Observations, continued from previous Report.

Observer—W. H. Wood.

Place of observation—Birmingham

March 1869.

Date	Hour, G.M.T.	Mag. as per stars.	Colour.	Duration.	Apparent Path.		Accordant Radiant.	Remarks.
					From	To		
18	P.M. 10 ^h 8 ^m	>1	Yellow	secs. 2.5	π^0 2	Leonis to θ Hydrae, +5°	M(1 ₂) or Q II(1)	Tail. See remarks for previous month below.

April.

10	h m 9 37	>1	White, Yellow	2.5	$\alpha = \delta =$ 107° + 36°	to γ Geminorum	M _{4,5}	Irregular flight and decreasing speed.
10	10 26 A.M.	4	Blue	0.5	μ to α Persei	A _{3,4} or S(1)		One meteor per hour
11	12 34	1	Pale blue	1.0	π Ursæ Majoris, towards μ Lynceis, path 25° +	Q II ₂ or G D ₂		Intercepted view.
20	P.M. 10 21	1	White	1.0	Polaris, Capella 2 to Capella	N(8)		10th overcast.
20	10 38	Sirius	White	0.75	Capella towards γ Gemi- norum.	N(5)		Imperfect view.
20	11 3	2	Blue	1.0	θ to ξ Hierculis	N ₈ or D G ₂ ...		Slow.
20	11 6	4	Yellow, then red	1.5	$\alpha = \delta = \alpha = \delta =$ 208° + 26° to 306° + 28°	S G(1)		Tail; slow. Meteor pear-shaped; burst with a flash.
20	11 38	2	Blue	1.0	$\alpha = \delta = \alpha = \delta =$ 237 0 to 245 0	S ₄		10th overcast.
20	11 38	2	Blue	0.5	$\beta \alpha$ 2 Ophiuchi to θ Serpentis	S _{5,6}		See remarks below.
20	11 52	>1	White	0.3	284° + 56° to γ Cephei	Q II ₂		Four meteors per hr. 7 in 1½ h; 21st, 11 to 11.30 P.M. no mtrs.

July.

Date	Hour, G.M.T.	Mag. as per stars.	Colour.	Dura- tion.	Apparent Path. From To	Accordant Radiant.	Remarks.
28	h m 11 15	1	Blue	secs. 0.5	α Sagittæ to A_2 Herculis ...	H.....	Sky hazy, moon 3rd qr. One meteor in half an hour.
30	11 35	3	Pale blue	0.5	λ Pegasi to π_2 Cygni	T ₍₁₎ or H	20th overcast.
30	11 37	>1	Intense blue.	0.2	ϵ Pegasi, path 1 ^s towards Delphinus.	R ₂	An elongated steel- blue flash.
30	11 44	3	Red.	0.75	γ Delphini to γ Delphini, ϵ Cygni 2	H.....	Overcast till 11.30, then 3 mtrs. in 20 ms. Night of 31st overcast.

REMARKS.

January 1st and 2nd, overcast at night; 3rd, 9-10 P.M., cloudy, with rain; lightning in N.N.W. horizon at 10^h 5^m, sky clear after 10 P.M.; no meteors in three-quarters of an hour.

April 15th, 10^h-11^h P.M. and after, fine display of Aurora Borealis; streamers, pink, green, and crimson colours, reached and radiated from the zenith, seen simultaneously in the U. S., America.

The Meteoric Shower of April 20.

There was a pronounced display of Meteors on this date at the rate of four meteors per hour for one observer, showing no tendency to maximum further than an absence on the succeeding night. The night was clear and moonlight after 10^h, moon 1st qr. There was no prominent radiant, but a feeble emission from seven or eight radiants common to the month, and mentioned in the list of meteors.

July 15th and 16th, from 10^h 30^m till 11^h 30^m P.M., sky cloudy at times, remaining clear about zenith; no meteors seen. 17th and 18th, overcast at 10^h 30^m P.M. 19th, sky clear, moonlight 10^h 30^m-11^h; no meteors.

Notices of Meteors from Newspapers, 1869.

An aërolitic fall in Sweden, mid-day, January 1st.

Large meteor (?) seen at Weston-super-Mare, Jan. 3rd.—“A meteor of unusually bright appearance between the hours of 9 and 10 shot from the heavens and disappeared beneath the waves. So vivid and instantaneous was the appearance and disappearance of the meteor that, although seen by a number of persons, there were many speculations as to its real nature. Many, by whom the reflection alone was seen, were of opinion that it was a vivid flash of lightning, whilst others thought it a rocket of unusual magnitude.”—*Bristol Daily Post*.

Jan. 13, 1.20 A.M.—A bright meteor observed at Brighton in W. of N.; two detonations in three minutes; meteor calculated, according to sound, to have burst thirty miles from observer.—Writer in ‘Standard,’ Jan. 14.

The same seen at Hampton, rising in N. Colour, indigo.—Writer in ‘Standard.’

April 3rd, between 4^h and 5^h A.M., a large meteor seen in Scotland. (See enclosed paragraph from ‘Lloyd’s News,’ and various other papers.)

May 31, 11.5 P.M., a large meteor seen at Norfolk, also at London. (See ‘The Times’ of June 2nd and 3rd, also the ‘Standard’ of June 3rd, and other papers.)

Action seen at New York.

May 20th, at night a meteor equal to the full moon was seen at New York. It changed colour from red to green and burst into fragments. It cast deep shadows, and had a long tail. Appeared 10° N.N.W. of α Aquilæ; path 30° N. westerly. --From American papers.-- *Morning Star*, June 3rd.

Report on the best means of providing for a uniformity of Weights and Measures, with reference to the Interests of Science. By a Committee, consisting of Sir JOHN BOWRING, *F.R.S.*, The Right Hon. C. B. ADDERLEY, *M.P.*, SAMUEL BROWN, *F.S.S.*, Dr. FARR, *F.R.S.*, FRANK P. FELLOWS, PROFESSOR FRANKLAND, *F.R.S.*, PROFESSOR HENNESSY, *F.R.S.*, JAMES HEYWOOD, *F.R.S.*, Sir ROBERT KANE, *F.R.S.*, PROFESSOR LEONE LEVI, PROFESSOR W. A. MILLER, *F.R.S.*, PROFESSOR RANKINE, *LL.D.*, *F.R.S.*, C. W. SIEMENS, *F.R.S.*, Colonel SYKES, *F.R.S.*, *M.P.*, PROFESSOR A. W. WILLIAMSON, *F.R.S.*, JAMES YATES, *F.R.S.*, Dr. GEORGE GLOVER, Sir JOSEPH WHITWORTH, *Bart.*, *F.R.S.*, J. R. NAPIER, H. DIRCKS, J. V. N. BAZALGETTE, W. SMITH, Sir W. FAIRBAIRN, *Bart.*, *F.R.S.*, and JOHN ROBINSON :—PROFESSOR LEONE LEVI, *Secretary*.

Your Committee have much pleasure in reporting that during the year considerable progress has been made towards the assimilation of weights and measures in all countries. As briefly stated last year, the North-German Confederation, by a law dated 13 June 1868, adopted the metre as the basis of measures and weights, and they resolved to take as the primary standard measure of length the platinum bar in the possession of the Prussian Government, which in the year 1863 was found by a Commission appointed by the French and Prussian Governments to be equal to 1.00000301 metre at the temperature of melting ice by comparison with the metre deposited at the Archives in Paris. Whilst adopting the metric nomenclature, the North-German Confederation added corresponding idiomatic names wherever possible, as, for instance, the Metre is also called the "Stab" or "Ell," the Centimetre the new "Zoll" or "Inch," the Millimetre the "Strick" or "Line," the Dekametre the "Kette" or Chain, the Litre the "Kanne" or Pot, the Hectolitre the "Zass" or Cask, the half Kilogram the "Pfund" or Pound, and the 50 Kilograms or 100 pounds the "Zentner" or Hundred-weight. In the United States the use of metric weights and measures has been rendered legal, and they are employed in all post-offices exchanging mails with foreign countries. In the Postal Convention with this country, signed at London on the 18th June 1867, the authorized weight of a single letter was stated to be half an ounce in the United Kingdom, or fifteen grammes by the metrical scale in the United States. It were much to be desired that the Post-Office of this country would second the enlightened opinion of the Americans and adopt fifteen grams as the minimum weight of letters sent to foreign countries. But still greater progress has been made in the introduction of the Metric System into India. The question of revising the Indian system of weights and measures had engaged the attention of the Government of India at various periods since 1837, and, in consequence of representations from the Madras Government and the Chambers of Commerce, the Government of India passed a resolution in 1864 authorizing

the appointment of local Committees in each Presidency to deliberate and report on the whole matter, with instructions to submit their views to the Central Committee at Calcutta for their consideration. In course of time, when these answers were received, it was found that in Madras and Bombay, the North-west Provinces and the Punjab, the Committees were in favour of a uniform system, based on the Imperial, their recommendation being that the unit of weight should consist of a *Socr* fixed at two lbs. avoirdupois, that the Imperial quart should be the unit of capacity, and the Yard and Acre the units of linear and superficial measure. The Bengal Committee, however, thinking that the days of the Imperial System were numbered, and that when all the rest of the world had adopted, or is about to adopt, the French Metric System it would be a retrograde step to adopt the English weights and measures, proposed the gradual but complete adoption of the French Metric System, and their recommendation received the support of the Bengal Government.

On the 1st October, 1867, Colonel Strachey, the President of the Central Committee, with the view of bringing forward an expression of public opinion, published a memorandum in which he supported the proposal of the Bengal Committee. In his opinion, the assimilation of the English weights to those of France was a mere question of time, and the existing English system could not last, and he therefore advocated the adoption of the French kilogram as the basis of the new system of weights in India. But Colonel Strachey's memorandum did not meet with the assent of a majority of the Committee, and he retired from it almost at the beginning of its labours, whereupon the Committee, with a new President, completed their labours, and concluded by recommending a new system based on Imperial units with decimal multiples and binary divisions. Thus the question stood when a Deputation from your Committee and the Council of the International Decimal Association waited on Sir Stafford Northcote, the then Secretary of State for India, for the purpose of urging the importance of introducing the Metric System in India; and it is gratifying to your Committee to state that, in a despatch dated 1st Feb. 1868, in conveying to the Government of India a full report of the representation of the Deputation, Sir Stafford Northcote wisely urged that whilst it would be better for the Committee to endeavour to establish a system more nearly approaching the best theoretical system than to adopt the English, the Government should be cautious not unduly to sacrifice practical convenience to theoretical symmetry. Soon after this a change of opinion appears to have taken place in the Indian Government. A decisive minute was made by the Commander-in-Chief, Sir W. R. Mansfield, dated 5th September 1868, in favour of the Metric System. The same was confirmed by the Governor-General, Sir John Lawrence; and after the subject had been fully discussed in Council, the whole matter was summed up in a despatch to the Secretary of State for India, recommending that the new unit of weight should be a *Socr* equal to the Kilogram, or 2.205 lbs. avoirdupois, and that a system of decimal multiples and subdivisions of the unit of weight should be accepted as a fundamental part of the new scale to be recognized by law. The Government of India further urged that the best preparation for the general adoption of the new metric weights would be their introduction and authoritative use in the first instance by all the Departments of the Government, by all Municipal bodies, and on the Railways. On the receipt of this despatch with the accompanying documents, the Duke of Argyll, the new Secretary of State for India, remitted the whole question to the Board of Trade, and asked them whether any measure is under consideration for a change in the weights of

this country. At that time, the subject being under the consideration of the Standard Commission, the answer was delayed; but as it became known that the Commissioners were favourable to the introduction of the Metric System, and that a decided opinion existed in this country in favour of advancing still further in the policy of the Permissive Act of 1864, the Duke of Argyll sent a despatch to the Indian Government approving of the introduction of the kilogram as the unit of weight throughout British India; and thus nearly 15,000,000 more of people will in a short time join the large family having one common system of weights, the adoption of the metric unit of length being certain to follow at no distant date. From India, with reference to the many colonies and dependencies of the empire, your Committee waited upon the Secretary of State for the Colonies, urging the advantage of at least a permissive law to use the Metric System in all the Colonies, and also the need of having the system taught in all their schools; and, with the consent and cooperation of the Secretary of State, your Committee, in conjunction with the Council of the International Association, sent a letter to all the Governors of the Colonies to the same effect. Judging from the great success achieved in India, we trust it will not be long before a decided uniformity of weights and measures shall be realized in Canada and Australia, the Cape and the West Indies, Malta and Gibraltar, in short in every colony of the empire.

In their last Report your Committee alluded to the unsatisfactory condition of the law in this country, which, whilst making it permissive to make contracts on the terms of the Metric System, made no provision for the stamping of metric weights and measures in general use. This anomaly having been brought by your Committee to the notice of Her Majesty's Government, the subject was remitted by the Board of Trade to the Standard Commission for their consideration, and your Committee are pleased to state that the second report of that Commission, just published, recommends the removal of every difficulty and the full and legal introduction of the Metric System. The resolution of that Commission on the subject is as follows:—

“Considering the information which has been laid before the Commission, of the great increase during late years of international communication equally in relation to trade and commerce, of the general adoption of the Metric System of Weights and Measures in many countries both in Europe and other parts of the world, and more recently in the North-German Confederation and in the United States of America, of the progress of public opinion in this country in favour of the Metric System as a uniform international system of weights and measures, and of the increasing use of the Metric System in scientific researches and in the practice of accurate chemistry and engineering construction, we are of opinion that the time has now arrived when the law should provide and facilities be afforded by the Government for the introduction and use of Metric Weights and Measures in the United Kingdom, and that for this object Metric Standards, accurately verified in relation to the primary Metric Standards of Paris and deposited in the Standard Department of the Board of Trade, should be legalized, and that verified copies of the official Metric Standard should be provided by the local authorities for inspection of such districts as may require them.” The Commissioners were not favourable to the compulsory measure on the subject; but they recommended that customs duties should be allowed to be levied by Metric Weights and Measures as well as by Imperial weight and measure; that the use of the Metric System concurrently with the Imperial System should be adopted by other public departments, especially the Post-Office, and in the publication of the principal results of the statistics of the Board of Trade, as well as for the

admeasurement and registration of the tonnage of shipping; and that Mural Standards of the Metric System as well as of the Imperial System be exhibited in public places. Your Committee regret the recommendation of the Commissioners to maintain for an indefinite time two legal systems in general use, it being subject to trouble and confusion. Nor do they agree with the reason assigned for any hesitation in this matter. It is asserted that there is no immediate cause for a change for the purpose of internal trade. But what say the Chambers of Agriculture and the Chambers of Commerce on the subject? The Barnstaple Farmers' Club recently petitioned Government in the following terms:—

“That your Petitioners, in common with the rest of the community, and more especially of the farmers, suffer much needless disadvantage, and are burdened with much unnecessary labour, by the great variety and complicated character of the legal, and still more of the customary, Weights and Measures in use in the United Kingdom, which add much to the number and difficulty of the calculations required in business transactions, and deprive your Petitioners of a great part of the benefit to be derived from the publication of the prices current at the different markets in different parts of the country.

“That while under different heads, such as Long Measures, Land Measures, Liquid Measures, Dry Measures, and Weights of different kinds, for different sorts respectively of lengths, of surfaces, of work, and of articles, dry and liquid, there are at least ten distinct sets of well ascertained, though utterly unsystematic, Weights and Measures recognized by law, besides an unknown multitude of customary Weights and Measures in use, in different localities in the United Kingdom, your Petitioners hear with envy of the superior facilities enjoyed by their rivals abroad in those foreign countries where a uniform Decimal System, comprising five series only, all equally easy to be learnt and all founded on the same scientific basis, has been established by law for the measurement respectively of length, of surface, of capacity, of solid bulk and of weight—a system which, owing to its obvious convenience, has either already become, or is rapidly becoming, general in practice wherever legally established.

“That this System (known as the ‘Metric,’ because wholly based on the Metre) was unanimously recommended in 1862, after a full inquiry, by a Committee of the House of Commons, comprising distinguished men of all political parties; and has already been adopted in its entirety by countries with a population of nearly 150,000,000, and a trade with the United Kingdom of nearly £180,000,000 sterling, and adopted in part by countries with a population of nearly 70,000,000, and a trade with the United Kingdom of £50,000,000, each class of countries comprehending some of the most highly civilized nations in the world, and each, as might be expected, continually receiving additions, notwithstanding the refusal hitherto of this country and the United States to do more than render the use of Metric Weights and Measures permissive, and that of Russia to recognize it at all.

“The existing confusion in Weights and Measures in this country and its Indian and Colonial Empire, equally complained of by the opponents and supporters of the Metric System, renders the present time, in the opinion of your Petitioners, particularly favourable for its legal adoption in its entirety; since a change to this, the simplest, most convenient, and most widely used System ever yet known, would cause hardly more trouble or inconvenience than would the rigid general enforcement of our cumbrous and utterly irrational Imperial set of Weights and Measures.

“Your Petitioners therefore humbly pray your Honourable House to take

measures for rendering the use of the Metric System not only legal but compulsory, at the earliest practicable period, throughout the United Kingdom and as many as possible of its dependencies."

The Scottish Chamber of Agriculture have deliberated on the subject of the grievance of having so many weights and measures in use. Grain is somewhere sold by the quarter or bushel, and elsewhere it is weighed and sold by the cental or other weight. The practice differs in every county, nay in every market, in the United Kingdom. The Royal Commissioners further urge, as a reason against the immediate complete introduction of the Metric System, that there are nearly thirty millions of ordinary weights and measures of the existing Imperial System now in common use. But how many of these are altogether unreliable? And is the temporary inconvenience of having to substitute new weights and measures to be considered a sufficient reason for delaying a reform of such importance to the trade and interests of the empire? The example of France and all countries where the Metric System has been introduced points out that it is necessary, in order to facilitate the change, to indicate a time when the introduction of the change must be effective, and your Committee hope that when Her Majesty's Government bring forward a Bill on the subject, the Legislature will see the necessity of providing that after a definite time the concurrent use of the Imperial and Metric Systems shall cease, and the Metric be finally adopted as the new Imperial System of weights and measures in the United Kingdom.

Your Committee have already observed that the Royal Commissioners recommended that the Metric Standards should be accurately verified in relation to the primary Metric Standards at Paris. These standards are a platinum metre and kilogram, deposited at the Palais des Archives in 1793. But it is not by these that new standards are now made. A copy of these standards was made at the same time to save the original standards, and for the purpose of verifying the Metric Standards of foreign countries where the Metric System is adopted; and this copy was first deposited at the Observatoire, and afterwards, in 1848, transferred to the Conservatoire des Arts et Métiers. The practice, therefore, is to verify any new standard by that copy, which, notwithstanding the lapse of time, differs very little from the standard of the Archives. It is objected, however, to such a practice, first, that it is inconvenient in all cases to resort to Paris for such verification; second, that if each country prepares its own standards and in its own way these will be found to differ from one another, and there may be not one but many metres; and, third, that the standards themselves are not complete. Upon this subject your Committee have recently received a Report of a Committee of the Physico-Mathematical Department of the Academy of Sciences of St. Petersburg, recommending that the different States should be invited to nominate an International Commission for the purpose of preparing prototype standards of the metre, and so create a unit of measure truly universal and effectively international. Your Committee are glad to hear that M. de Jacobi, to whose able pen we owe the valuable Report issued by the Committee of Weights and Measures for the International Conference in 1867, will be present at this Meeting to advocate this suggestion. The mode of obtaining a correct standard is a question of administration which may be safely left to the Warden of the Standards; yet your Committee are of opinion that the Commission thus suggested may prove most beneficial, especially in endeavouring to correct any small scientific defects in the system itself, and in the weights and measures separately in connexion with it. Your Committee are happy in reporting that the Mural Standard, made under their direction, of the Metre

is highly appreciated, and during the year copies of the same have been forwarded for public exhibition at Norwich and Exeter, and to the Harvard University in the United States. Your Committee are desirous of making further grants of such Mural Standards, but the funds at their disposal do not allow them to use these efficient means for diffusing the knowledge of the Metric System. Your Committee have much pleasure in reporting that considerable stimulus has been given to the study of the Metric System by the prizes offered to the students passing the examination of the Society of Arts and the British and Foreign School Society on the subject; and that the prize of £10 offered for the best school-book on the Metric System was gained by W. C. Vaughan for an excellent treatise on the subject, which your Committee trust will soon be published and become extensively useful.

Upon the subject of International Coinage no step has been taken since the report of the Royal Commissioners.

The Chancellor of the Exchequer, however, has recently enunciated his views in favour of imposing a seigniorage of about one per cent., and of taking it from the coin with the view that the sovereign may become identical with the 25-franc piece. In his opinion, whilst the sovereign would still remain as a current coin in this country of exactly the same value as now, it would have the additional advantage that it would be identical in value with the 25-franc piece. The subject has been frequently before your Committee, but they conceive that a general understanding on this and many other points of extreme difficulty and magnitude should be arrived at by those conversant with the practical administration of the mints in different countries before the subject is deliberately submitted for the approval of the country; and your Committee content themselves in echoing the recommendation of the Royal Commissioners on International Coinage, that another International Conference may speedily be held for that purpose. The question is well worthy of the attention of the British Association, and your Committee recommend that the Council of the British Association should make a representation to that effect to Her Majesty's Government. In conclusion, your Committee are persuaded that their efforts have not been in vain in stimulating the early realization of one uniform system of weights, measures, and coins in all countries, an object of the highest importance in the interest of science, education, commerce, and peace; but their task being far from complete, and with a view to labour still further towards that end, they recommend the reappointment of the Committee, with a grant of at least £50 for the purpose.

Report on the Treatment and Utilization of Sewage. Drawn up by Dr.

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PROBABLY one of the most important results of modern scientific inquiry is the general recognition of the fact that attention to the hygienic requirements

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of towns and populous places has a great influence on the preservation of health and life. Hygienic measures calculated to prevent disease have therefore come to be regarded even of more importance than the knowledge gained by two thousand years' experience in the art of medicine.

Pure air and water are two of the most essential requirements of all populous places. The removal of water from the surface and from the subsoil by some kind of drainage has also been found essential to the healthiness of a place; but the thing most of all important in its influence on the sanitary condition of towns &c., and as affecting the purity of the air and water, is undoubtedly the mode in which the excretal refuse of their population is dealt with.

Even in the most primitive states of society it has always been found necessary to dispose of excreta and other refuse materials from dwellings in such a manner as to prevent them from becoming a nuisance; and the most simple mode of effecting that object was probably the plan prescribed by Moses to the Jews*.

The fact that animal excreta are useful as manure has also led, in many cases, to the adoption of some plan of dealing with them for that purpose, by which their accumulation in the vicinity of dwellings would be prevented to a great extent; and in that way no great difficulty would be experienced in thinly populated places in devising simple measures sufficient to meet all requirements. Under such circumstances the mode of effecting the object in view would be a matter to be determined and carried out by the individual residents of a place. But wherever the population became concentrated in villages or towns, difficulties arose as to the disposal of excreta or their immediate removal and use as manure, in consequence of which it became a practice almost universal to allow them to collect, together with other refuse, in pits dug in the ground near each house or group of houses, and then at intervals to remove the accumulated contents of these pits for use as manure. As the magnitude of towns increased, the difficulty of thus dealing with excretal refuse became greater, and the offensive consequences of its accumulation near dwellings more sensible. Hence this subject became more and more a matter to be dealt with by the local authorities, at first by regulation of the practices adopted by the inhabitants of a place, and eventually it became a duty to be provided for and performed by the authorities themselves in such a way as to ensure the common convenience and well-being of the population.

However, the full importance of this subject in other respects was far from being appreciated until within the last thirty or forty years. It is only within this recent period that there has been anything like an adequate recognition of the fact that the sanitary state of dwellings and towns, the health and mortality of their population, the condition of rivers, and other matters of importance are, as a general rule, largely influenced by the practices adopted in regard to excretal refuse. Within that period inquiry and experience have shown that excretal refuse, besides being offensive and, in some cases, a great nuisance when accumulated in a state of putrefaction or decay near dwellings, may be, and often is, a source of vast injury to the public health. Opinions may vary as to the precise mode in which that influence is exercised—whether by the evolution of deleterious gases, by the pollution of water, by the development of those minute organisms which are now very generally considered to be the media of infection, or in all of these ways conjointly; but there is no longer any doubt or difference of opinion as to

* Deuteronomy, ch. xxiii. ver. 12 *et seq.*

the general truth that, in regard to the mode of dealing with excretal refuse, the sanitary point of view is far more important than any other. If, then, the weightiest question to be solved by a municipal body be, how best to preserve the health and life of the population committed to its charge, it is evident that one of the first duties of such a body is that of providing for the disposal of excretal refuse in a suitable manner. The recognition of this sanitary axiom has been so imperatively enforced during the present century by the frequent prevalence of epidemic diseases, such as cholera and fever, that it may perhaps now be regarded as unquestionable, except where ignorance overcomes intelligence, and where mistaken notions of economy prevail.

Under this aspect the subject has lately attracted very general attention, not only in this country but also in most civilized countries abroad. It will therefore be desirable to recite briefly the circumstances under which excretal refuse may become a source of injury to health, and to trace the course events have taken in regard to this subject since public attention was first directed to the sanitary condition of towns, and since measures have been adopted with a view to its amelioration.

Besides the inconvenience and offensive character of the system of collecting excretal refuse in pits or vaults near dwellings, the evils consequent on that plan arose chiefly from the impregnation of the surrounding soil with decomposing material, and sometimes also from the pollution of water used for domestic purposes. The pits or reservoirs were in some cases provided with overflow channels or with drains, by which the liquid contents were discharged into a neighbouring watercourse or into a sewer; but in many cases that was unnecessary, where the soil was of a sufficiently porous nature to admit of the continuous free escape of liquid from the pits. By this natural drainage, according to the nature of the soil, the liquid portions of the excreta would permeate the soil and gain access to the wells, which were, as a very general custom, placed close to the pits where excreta were collected. Moreover this foul drainage would be augmented in many cases by the access of surface-water to the pits, especially during wet weather.

These evils were often much aggravated by the absence of any systematic drainage or sewerage of towns sufficient for the removal of subsoil water, which became stagnant and putrefied beneath the dwellings. Even where underground sewers existed they appear to have been intended only for the removal of surface-water; the connexion of house-drains with these sewers was prohibited, and it was penal to discharge or throw any excretal or other offensive refuse into rivers.

At that time the water-closets (introduced by Bramah in 1793) were very rarely in use; they had been adopted only in the better class of houses in towns, and then they were used in conjunction with underground vaults for receiving the material discharged from them. Their subsequent more general adoption, and the concurrent acquisition of a better and more copious water-supply, were no doubt largely conducive to domestic comfort and convenience; but, in regard to the condition of towns, these changes were attended with a decided aggravation of the evils arising from the use of vaults or pits as receptacles of excreta; for the drainage or overflow from these pits became continuous on account of the use of water in the closets, and it was no longer dependent on the occasional access of rain. Under these circumstances the pits or vaults became cesspools*, constantly charged with liquid, and in most cases they had no outlet into the sewers. Even so late as 1844 the Health

* This term appears to be of recent origin, as it is not to be found in old dictionaries.

of Towns' Commissioners state, in their first Report, that "in some of the larger and most crowded towns all entrance into the sewers by house-drains or drains from water-closets or cesspools is prohibited under a penalty;" while in other places, including part of the metropolis, the entrance of house-drains was deemed "the concession of a privilege subjected to regulations and separate proceedings with attendant expenses," tending either to restrict the use of sewers for the purpose of removing excretal refuse and the drainage from pits containing it, or to combine the advantages of this plan to the wealthy.

The removal of the domestic nuisance and incumbrance attending the use of privies and pits for collecting the refuse, by the introduction of water-closets, gave rise in this way to the creation of a *town nuisance*; the old town sewers or drains proved inadequate to the duty thrown upon them; for in some instances an improved water-supply was taken into a town without any means being provided for taking it out again. The pent-up overflow from cesspools, connected with water-closets, saturated the subsoil, the water of wells became permanently polluted, fertil water rose in the cellars of houses, rendering the air impure by its exhalations, sickness followed, and eventually there arose a loud outcry against the cesspool system as an intolerable nuisance, affecting not merely individual houses but the town generally.

The plan proposed as a remedy for this evil was the general adoption of water-closets, combined with a system of thorough town sewerage, the connexion of house-drains with the sewers being made compulsory on the owners of houses under certain conditions. By this means the necessity for allowing excretal refuse to accumulate at all near dwellings or within towns was to be done away with; this refuse was to be at once removed from dwellings into the sewers by a copious use of water, and swept rapidly through them out of the town with the waste water from houses and the surface-drainage.

By this plan the whole of the water entering a town is eventually polluted either by use or by admixture, and then constitutes what is now commonly termed town-sewage, the expeditious removal of which from the vicinity of towns is indispensable for the health of the neighbourhood.

This system, known as the water-carriage system, has been largely adopted in this country, and, as a consequence, both the drainage of towns and the removal of the excretal refuse have been in many cases effected by the same means. The utilization of this town-sewage as manure, by irrigating land, was contemplated at the outset, but it was not enforced, and it has been carried out only in a few cases, the sewage as a rule being discharged from the sewers into any adjoining river or into the sea, this being permitted so long as it does not create a nuisance. Individuals or towns injured by the discharge of sewage in this way were left to obtain what redress they could by legal means. The adoption of this system is well known to have given rise to much litigation, and many towns where it has been adopted have been placed in a very difficult position in consequence of injunctions by the Court of Chancery prohibiting the discharge of their sewage into watercourses.

Moreover the adoption of the water-closet and sewerage system of dealing with excretal refuse has been followed by a greatly augmented pollution of rivers, which is now acknowledged to have become an evil of national importance, and is still a subject of official inquiry. At this point, when the measures adopted for removing successively the domestic nuisance and the town nuisance, arising from the disposal of excretal refuse, have given rise to a national nuisance, it has become a very serious matter to determine what

is to be done with the sewage of towns. The importance of this question is shown by the fact that, besides engaging the attention of the late General Board of Health, besides being frequently discussed in Parliament and by the various local authorities throughout the kingdom, it has within the last thirteen years given rise to the appointment of three Royal Commissions charged with the duties of investigating the subject and of suggesting remedial measures, viz. :—

I. The Sewage Commission, dated 5th January 1857, “to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses,” from which three reports have issued, bearing date March 1858, August 1861, and March 1865. The conclusions the Commissioners arrived at were to the effect that the direct application of sewage to land favourably situated, if judiciously carried out and confined to a suitable area exclusively grass, is profitable to persons so employing it; that where the conditions are unfavourable, a small payment on the part of the local authorities will restore the balance; that this method of sewage application, conducted with moderate care, is not productive of nuisance or injury to health.

That methods of precipitation are satisfactory merely as a means of mitigating a nuisance.

That the only radical way of restoring the rivers to their original purity is to prevent the discharge of foul matters into them, and especially the discharge of sewage and other refuse of large towns.

That the right way to dispose of town sewage is to apply it continuously to land, and that it is only by such application that the pollution of rivers can be avoided.

That the magnitude of a town presents no real difficulty to the effectual treatment of its sewage, provided it be considered as a collection of smaller towns.

II. The Rivers' Commission, dated 18th May 1865, “to inquire how far the present use of rivers for carrying off the sewage of towns, populous places, &c. can be prevented without risk to the public health, and how far such sewage &c. can be utilized,” from which three reports have already issued, bearing date March 1866, May 1867, and August 1867, and further reports are expected.

And III. The Royal Sanitary Commission, dated November 1868, “to inquire into and report on the operations of the sanitary laws for towns, villages, and rural districts in Great Britain and Ireland, so far as these laws apply to sewerage, drainage, water-supply, removal of refuse, prevention of overcrowding, and other conditions conducive to the public health.” This latter Commission is now engaged in its first proceedings, which are limited to the consolidation and improvement of existing laws, and the establishment of a better recognized central control. It is expected that a preliminary report from this Commission will shortly appear.

The object of your Committee has been understood by its Members as that of supplementing the above-mentioned public inquiries, with special information, as to the local circumstances and practical experience of various towns throughout the kingdom, and with other positive data relating to the subject, such as the Royal Sewage Commission have pointed out as requisite to be ascertained.

Your Committee, in entering on its duties, came to the conclusion that since town sewage, as it is now most commonly known in this country, is a source of nuisance, inconvenience, and injury to health, chiefly by reason of

its containing the excretal refuse of the population, it was desirable the term sewage should not be restricted to the liquid discharged from sewers in places where there is a thorough system of sewerage combined with water-closets and a copious supply of water, or, in other words, where the water-carriage system of disposing of excretal refuse has been adopted, but that it should, for the purposes of this inquiry, be understood as comprising excretal refuse in any state. This extended application of the term sewage seemed to be the more desirable, since there are many towns and places that are at present debarred from adopting any measures for dealing with their excretal refuse by doubts entertained as to the sanitary efficacy of such a system as that just mentioned, and by a knowledge of the difficulties attending the disposal of the sewage produced under that system. In order to ensure an explicit understanding on this point in all correspondence and communications, the following resolution was passed at a meeting of your Committee on the 5th of January, 1869, viz.:—

“That the Committee do interpret the word ‘sewage’ in the instructions of the Association as meaning any refuse, from human habitations, that may affect the public health;” and this interpretation of the term was specified in all applications for information.

Bearing in mind the circumstance, already referred to in the introductory remarks, that formerly town-sewers were essentially drains, the objects of which were simply and exclusively the removal of surface- and slop-water by the most direct course to the nearest stream, as well as the fact that such sewers, originally intended only for drainage, have in various ways come to be confounded with and used as sewers for removing excretal refuse as well as the surface and subsoil water, it was, for these reasons, considered to be especially important to make a marked distinction between drainage and sewerage, and, with that object, to designate the removal of surface and subsoil water from land by permeable channels “drainage by drains,” and the removal of excretal or other refuse from dwellings, factories, streets, &c., by water through impervious conduits, “sewerage by sewers.” According to this distinction, a drain should be understood as a permeable channel adapted throughout its entire length to remove water from the soil surrounding it; while a sewer should be understood as a channel sufficiently impermeable to be adapted for conveying away house refuse without allowing either the refuse to escape through its sides or water to penetrate from without.

One of the first steps taken by the Committee was to apply to Her Majesty’s Secretary of State for the Home Department for his assistance in obtaining information from foreign countries respecting the practices prevailing abroad for disposing of the refuse of towns, villages, public institutions, factories, dwellings, &c., and having reference to the sanitary condition of the districts in which they are situated, the state of rivers, or the support and increase of the produce of the soil; to this application Mr. Secretary Bruce has given effect by transmitting from time to time very valuable information, received from the following countries.

Received from the Home Office.

15th March, 1869. From Hamburg.—1. Statement as to the sewerage in Hamburg. 2. Plan of sewers in Hamburg forwarded by Mr. Ward to Lord Clarendon.

16th March, 1869. From Saxe Coburg Gotha.—Statement as to removal and disposal of refuse from dwellings in Gotha, in a despatch from Mr. C. T. Barnard to Lord Clarendon.

- 25th March, 1869. From Holland.—1. Statement addressed by M. Boest van Limburg to Vice-Admiral Harris. 2. Statement of the Minister of the Interior at the Hague.
- 30th March, 1869. From Bavaria.—1. Despatch from Prince Hohenlohe to Sir Henry Howard. 2. Die Kultur-Gesetze Bayerns unter der Regierung Maximilian II. (The agricultural laws of Bavaria under the government of Maximilian the Second.) 3. Die bayerische Gesetzgebung und Verwaltung im Bereiche der Landwirthschaft. (Legislation and administration relating to agriculture in Bavaria.)
- 14th April, 1869. From Baden.—1. Despatch from Mr. E. W. Cope to Mr. G. I. R. Gordon, describing the modes of emptying cesspools in Carlsruhe and Freiburg, and disposing of the refuse. 2. Statement addressed by Baron Freidorf to Mr. E. W. Cope as to the treatment of house-refuse in the Grand Duchy. 3. Vertrag über die Vornahme und Besorgung der geruchlosen Entleerung der Abtrittsgruben, Abfuhr des Strassenkehrichts und der Haushaltungsabfälle, sowie der Reinigung der unterirdischen Kanäle in Karlsruhe, nebst einem Anhang enthaltend die hierher bezüglichen ortspolizeilichen Vorschriften. (Contract relating to the inodorous emptying of cesspits, removal of rubbish from the streets and dwellings, as well as the cleansing of the underground sewers in Carlsruhe, together with an Appendix containing the local regulations relating thereto.)
- 26th April, 1869. From Saxony.—1. Statement respecting the treatment of town-refuse addressed by M. de Bosse to Mr. Hume Burnley, with extracts from the official regulations on this subject.
- 14th April, 1869. From Prussia.—1. Despatch from Baron Thiele to Lord Aug. Loftus, stating that the practice in use for transporting and disposing of the refuse of towns and villages in Prussia are at present very different, and in general unsatisfactory, and that very great difference of opinion prevails as to the necessary regulations to be made. 2. Gutachtliche Ausserungen des Landes-Melioration Bau-Inspectors Röder und des Professors der Agricultur-Chemie Dr. Eichhorn über die Verwerthung der Dungstoffe der Stadt Berlin für die Bodenkultur mit Bezugnahme auf das Project des geheimen Baurathes Wiebe "Ueber die Reinigung und Entwässerung der Stadt Berlin." (Report of Herr Röder, Inspector of Building and Improvements, and Dr. Eichhorn, Professor of Agricultural Chemistry, on the utilization of excreta from Berlin for agriculture with reference to the plan proposed by Herr Wiebe "On the Cleansing and Drainage of Berlin.") 3. Proposition des Landes-Oeconomic Rathes Weyhe betreffend die projectirte Kanalisierung Berlins und die Anwendung eines zweckmässigen Systems zur Entfernung und Nutzbarmachung der Dungstoffe der Stadt im Interesse der Bodenkultur, u. s. w. (Memorandum by Hr. Weyhe in reference to the proposed sewerage of Berlin, and to the application of an efficient system of removing excreta from the town, and utilizing them for the advantage of agriculture, &c.) 4. Die Abfuhr und Verwerthung der Dungstoffe in verschiedenen deutschen und ausserdeutschen Städten, und darauf bezügliche Vorschläge für Berlin. Bericht der von Seiner Excellenz dem Minister für die landwirthschaftlichen Angelegenheiten Herrn von Selchow ernannten Kommission C. von Salviati, O. Röder, und Dr. Eichhorn. (Report of the Commission appointed by the Minister of Agriculture to inquire into the removal and utilization of excreta in various German and other towns, and to consider the plans proposed with those objects for Berlin.) 5. Ueber die Kanalisation von Berlin. Gutachten der Königl. wissenschaftlichen Deputation für das Medicinal-

wesen nebst einem Nachtrage mit zusätzlichen Bemerkungen von Rud. Virchow. (Report of the Royal Medical Commission on the Sewage of Berlin, with Appendix and remarks by Rud. Virchow.)

- 18th May, 1869. From Switzerland.—1. Report from the Department of the Interior at Berne to the Federal Council, forwarded by Mr. Bonar to Lord Clarendon, and containing information collected from the municipal bodies of various Swiss towns. 2. Ueber Anlage städtischer Abzugs-Kanäle und Behandlung der Abfallstoffe aus Städten. Von A. Bürkli. (The construction of town-sewers, and treatment of the refuse of towns.) 3. Ueber die Kloaken-Verhältnisse der Stadt Berne von Dr. Adolf Vogt. (The sewerage of Berne.) 4. Die Wasserverhältnisse Berns in Beziehung zu den Infectionen Krankheiten von Dr. A. Ziegler. (The connexion between water-supply and infectious diseases in Berne.) 5. Instruction sur l'Assainissement des habitations et des rues. (Directions for improving the sanitary condition of dwellings and streets.) Drawn up by the Special Sanitary Commission appointed by the Municipality of Lausanne in 1867, and approved by the Municipal Board of Health.
- 20th May, 1869. From Austria and Hungary.—1. Despatch from the Minister of Foreign Affairs at Vienna to Lord Blomfield, describing the methods in use in both portions of the empire.
- 20th May, 1869. From Belgium.—1. Report from M. Vanderstichelen to Mr. Savile Lumley on the regulations for disposing of refuse in towns and villages in Belgium. 2. Police des Etablissements dangereux insalubres ou incommodes. (Regulations concerning works that are dangerous, unhealthy, or a nuisance.) 3. Mémoire sur la révision de la Législation des cours d'eau non-navigables ni flottables, &c. (Memoir on the revision of laws relating to watercourses that are not navigable.) A prize essay by M. Jules Sauveur.
- 20th May, 1869. From Sweden.—1. Despatch from Count Wachtmeister to Mr. Jerminham. 2. Report presented to the Grand Governor in Stockholm by the Board charged with the removal of refuse from the town. 3. Statement of expenditure and receipts of the Board during 1868. 4. Öfver-Ståthallare-Embetets Kungörelse angående särskilda ordningsföreskrifter för Stockholm utöfver hoad Kongl. Majts. Nädiga Ordningstadga för Rikets Städer innahåller, 11 Jan. 1869. (Regulation issued by the Grand Governor respecting removal of refuse.) 5. Project for removing refuse by railway as suggested to the Town Council of Stockholm by M. A. Hanongren.
- 20th May, 1869. From Denmark.—1. Despatch from Sir C. L. Wyke to the Earl of Clarendon, stating that no precise data can be obtained.
- 20th May, 1869. From Turkey.—1. Extract from Mr. Elliot's despatch, stating that in Turkey matters are conducted in the most primitive manner.
- 20th May, 1869. From Greece.—1. Despatch from the Minister of Foreign Affairs at Athens to the Hon. E. M. Erskine, stating that the refuse of dwellings is generally carried out of the towns in carts at the expense of the municipal authorities, and that its application in agriculture is very limited.
- 20th May, 1869. From Russia.—Statement of the regulations as to removal of town refuse and its application in agriculture, for preventing pollution of water and other matters relating to public health.
- 20th May, 1869. From the United States of America.—1. Despatch from Mr. Thornton to the Earl of Clarendon, containing information furnished by H. M. Consuls at some of the principal cities in the United States. 2. Annual Report from the Superintendent of Health in Boston to the

City Council for the year 1868. 3. Copies of ordinances issued by the Health Office and Mayor of the City of Boston in reference to house-offal, ashes, &c. The construction of vaults and privies. Sanitary visitation. 4. Description of a plan for the Drainage of Washington proposed by Mr. P. H. Donegan. 5. Letter addressed from the Mayor's office of the City of Salem to Mr. Consul Lousada, stating that a system of sewerage is being constructed in that city by which the whole of the town-refuse will be carried into the two rivers between which it stands, instead of being collected, as heretofore, in vaults or cesspits, and carted away at intervals to serve as manure. 6. Municipal Register containing the ordinances, regulations, &c. of the City of Salem for 1867.

20th May, 1869. From Württemberg.—1. Despatch from Mr. Gordon to the Earl of Clarendon. 2. Strassen-Polizei-Vorschriften für die Stadt Stuttgart. (Police regulations for the streets of Stuttgart.) 3. Report on the disposal of refuse in towns and dwellings, addressed to the Minister of the Interior by the Central Board of Agriculture in Stuttgart.

It appears from these documents that in most cases (both in town and country places) the use of privies is very general, water-closets being rare even in large towns, and that the usual method of dealing with human excreta is to allow them to collect in pits (*Abtrittsgruben*, fosses), which are sometimes drained, either naturally by the permeable character of the soil, or artificially, so that most or all of the liquid portion of the contents of the pits flows away or infiltrates the surrounding soil. Frequently privies are built over rivers, with the object of getting rid of the excreta at once; and at some places methods still more objectionable are adopted, many houses are without either water-closets or privies, the common custom being to use nightstools, which are emptied into pits near the house; thus, for instance, in Berlin, with a population under 600,000, there are said to be no less than 50,000 nightstools in daily use.

Only in some few foreign towns is there any system of sewerage for the removal of excreta by means of water; this is the case in Hamburg, Paris, Brussels, Hanover, Washington, Philadelphia, San Francisco, and some other American towns to a greater or less extent. In some other towns modified arrangements of the privy and pit system have been to some extent adopted. These consist in substituting for the ordinary pit either a fixed or a portable reservoir for receiving the excreta. These reservoirs are sometimes constructed with a drain by which the overflow or the liquid contents escape, and sometimes they are both water- and air-tight, the discharge of the liquid contents into the sewers being prohibited. In some cases such reservoirs are constructed so as to receive only the excreta, and sometimes so as to separate the solid and liquid excreta; but they are also used in combination with water-closets, and sometimes they receive rain-water from the house-roofs &c. as well.

The contents of the fixed reservoirs are removed periodically in several different ways, and according to divers local regulations. Sometimes the contents are simply dipped out, and sometimes they are removed either by pumping into closed tank-carts with lift-pumps, or by means of a vacuum previously produced in the tank-cart. In some few cases the time that may elapse between the removal of the contents of these reservoirs is fixed by the local authorities. The portable reservoirs are from time to time removed and replaced by empty reservoirs, then carried outside the town, and their contents used as manure in some way. Both the fixed and portable re-

servoirs are frequently ventilated by means of shafts rising above the house-tops. Fixed reservoirs are used in Carlsruhe, Ostend, Antwerp, Strasburg, Berlin, Dresden.

Portable reservoirs are used in Gratz, Dresden, Leipzig, Strasburg, Berlin, Paris. Generally the contents of pits and of fixed or portable reservoirs are used as manure. In some cases each household pays for the removal of excretal refuse, in others the contents of pits and reservoirs are sold. At some places the town authorities pay for the removal of the refuse and street-sweepings. Thus in Carlsruhe, a town with about 25,000 inhabitants and 1400 houses, about £500 a year is paid to the contractor for this service, and the contractor sells the manure.

Sometimes a town derives some return from the excretal and other refuse removed and used as manure. In the town of Groningen the yearly profit amounts to about £1600, in Antwerp it is £2700, at Ostend £700. In Strasburg the cost of removal is only just covered by the sale of the manure. The sale of the refuse from the barracks at Carlsruhe, where 2800 men were quartered, has realized a profit of £300 a year, and the attendant expenses amounted to about £40 a year.

According to experience in the neighbourhood of Berne, Basle, Munich, Zurich, Ghent, and other towns where excretal refuse is removed and used as manure, there is always a profit realized after payment of the cost of removal and transport; and it appears to be considered probable that the expense attending this system would be reduced by the adoption of portable reservoirs. In some other towns the cost of removal and transport exceeds the return; thus, in Stockholm, with a population of about 150,000, the expenditure amounts to £35,000 a year, and the income derived from the sale of the refuse as manure is £33,000 a year.

In Hamburg there is an extensive system of sewerage, and in a large part of the town the excreta are removed by water-carriage through sewers. In Brussels, Paris, Lausanne, and Lugano the water-carriage system is also more or less adopted in some form adapted to local conditions. However, in the two latter towns water-closets are but rarely used, and in Basle likewise the privies are situated so as to discharge into the Rhine, or into one of its tributaries. In the case of Hamburg the water of the Elbe is stated to be much polluted by the discharge of sewage, but without any apparent serious influence on health. However, statistics furnished by the Secretary to the Hamburg Board of Health show that the rate of mortality has kept pace with the increase of population. In 1840, before the construction of the sewerage, the population was 137,000, with a mortality of 28 per thousand. In 1848 the population was 148,000, with a mortality of 22 per thousand; in 1859 the population was 174,000, with a mortality of 26 per thousand; and in 1866 the population was 195,000, with a mortality of 28 per thousand.

The general purport of the communications received from foreign countries is to show that the question as to the means by which excretal refuse may be disposed of and removed from dwellings, villages, and towns, so as to prevent nuisance or evil consequences as regards the sanitary condition of the locality, is, at least, quite as much an open and disputed question as it is in this country. In these documents there is abundant evidence that, wherever the subject has been considered, there is a strong, though vague sense of the injury to health resulting from the accumulation of excretal materials in pits &c. within populous districts, by the impregnation of the soil, by the pollution of rivers and well-water with drainage from such accumulations, or from the discharge of excretal materials into watercourses directly or indi-

rectly ; and it appears to be generally admitted that these are serious evils that require to be remedied.

Besides these views as to the sanitary aspect of the subject, there is still more decisive evidence of the conviction that a vast quantity of material is now wasted which might be of great service in agriculture for sustaining and augmenting the fertility of cultivated land. There is, however, no instance in which decisive conclusions have been arrived at as to the best mode of dealing with town-refuse so as to secure a satisfactory state of public health, and at the same time admit of the agricultural value of that refuse being realized without concurrent disadvantages. It does not appear that any particular improved system of dealing with house-refuse has been generally adopted as a substitute for the old practice of collecting such refuse in pits with periodical removal of the contents ; neither is there any case where an attempted improvement has been long enough practised to furnish satisfactory evidence as to the efficacy of the means adopted, and their influence on public health. In both these respects it may safely be said that foreign towns are, as a rule, far behind some towns in this country.

The method of removing excretal refuse by pumping it into carts and carrying it out of the town to the neighbouring land, has in some instances been continued with satisfaction, while in other instances it has been abandoned after trial.

The plans of collecting and removing excretal refuse in portable closed reservoirs has been largely adopted in France, Saxony, Switzerland, and other countries ; but in no case is any specific information given as to the extent to which the liquid portion escapes, spontaneously or by drainage, to pollute the adjoining soil and watercourses, or how far the portion of the refuse that remains represents the original value of the excreta for agriculture. In some towns it is evident that only the solid excreta are used as manure ; thus in Zurich there is a system of sewerage which carries off both the rain-water and liquid drainage from gutters, houses, and reservoirs for collecting excreta. Probably in most cases, where cesspools or fixed and portable reservoirs are in use, the greater part of the liquid excreta drains away.

In some towns, as in Berlin for instance, the use of water as a means of transporting the refuse has been proposed, and it is still under consideration. Some of the scientific authorities deputed to inquire into the subject have, however, recommended that any general system of sewerage, based on that principle, should not be adopted, because of the increased difficulty it gives rise to in the realization of the value of the excreta as manure, and because of the anticipated prejudicial influences on the air of the district if the sewage were applied to land, and upon the water of rivers if the liquid refuse were mixed with it.

There does not appear to be, in any country, general or systematic legislation in reference to sanitary matters. Almost everywhere the regulations with that object are in the hands of the police or other local authorities ; and though the provisions relating to removal of refuse, cleaning of streets, &c. are often very minute and stringent, they are seldom or ever of such a nature as to deal effectually with those tendencies to unhealthiness which result from accumulation of excretal and other refuse material, especially in large towns or densely populated districts.

As to the precise conditions that affect the public health, the connexion between the sanitary state of towns and the drainage, water-supply, mode of disposing of excretal refuse, &c., there appears to be, even more than in this country, an absence of definite knowledge or of demonstrative evidence in

favour of any particular view, though at the same time there is everywhere in civilized countries an earnest consideration of these subjects in all their bearings—sanitary, municipal, and agricultural.

While this information was being collected from foreign countries, the Committee prepared a series of questions with the object of eliciting information as to the several cities, towns, and rural districts throughout the United Kingdom, so far as the means at its disposal would permit. These questions were sent to 340 local sanitary and sewer authorities, representing a population of about 10 millions. Up to the present time replies have been received from 107 places having an aggregate population of more than 4 millions.

Number and Population of Towns &c.

	Applied to.	Answered.
Towns with upwards of 100,000	16	8
„ „ between 100,000 and 50,000....	23	13
„ „ „ 50,000 and 20,000....	59	22
„ „ „ 20,000 and 10,000....	69	23
„ „ „ 10,000	134	33
Rural districts	39	8
	340	107

Total Area, Number of Houses, and Rateable Value.—Of the 107 places from which replies have been received, the total area of 78 of them is stated to be 413,218 acres. The areas of the remaining 29 places have not been specified.

In 93 of these places the total number of houses is stated to be 727,816, and their aggregate rateable value £14,849,556.

In fourteen instances no particulars were stated as to these points.

Water-supply.—It appears that the sources of water-supply in these places are as follow:—

	Number of towns.	Aggregate population.
Surface-wells.....	24	354,800
Springs	8	63,680
Springs and gathering-grounds	16	1,210,906
Gathering-grounds and wells	3	600,552
Gathering-grounds and rivers	2	59,000
Rivers and streams	26	843,140
Lakes	1	19,000
Artesian wells	12	263,500
Artesian wells, rivers, and surface-wells	2	446,000
No information given	13	393,746

Of these places, 80 are provided with waterworks,

27 are without waterworks, or give no definite information.

The quantity of water supplied per head of the population is stated to be as under:—

	Number of towns.	Aggregate population.
From 50 to 30 gallons.....	7	596,800
„ 30 „ 20 „	25	1,477,007
„ 20 „ 15 „	13	455,500
„ 15 „ 10 „	15	370,500
Under 10	3	42,500
Not stated.....	43	1,444,000

The largest amount of water supplied is in the case of Lynn, where it is stated to be 56 gallons per head daily, and the smallest amount is said to be supplied in the case of Stroud, where it is only 4 gallons per head.

Disposal of Excretal Refuse.—Of the 107 places there are 42 where the old system of using privies with pits for collecting the refuse is general, and 25 where it is partially adhered to. In 42 places water-closets are general, and in 25 places they have been adopted partially to a greater or less extent.

Sewerage.—Out of the 107 places there are only 11 where no system of sewerage exists; in the remainder the sewerage of the towns is either general or partial, but in some instances very defective.

	Number of towns.	Number of Houses.		Population.	
		Total.	Sewered.	Total.	Discharging into sewers.
Completely sewered	48	375,002	375,002	2,230,578	2,230,578
Partially sewered..	48	337,299	152,785	1,973,753	1,039,731
Not sewered.....	11	24,800	.....	145,000	
	107				

Of the places which are completely sewered there are,—

29 where water-closets are general.
 12 „ privies „ „
 7 „ both are used.

Of the places which are only partially sewered there are,—

12 where water-closets are general.
 22 „ privies „ „
 14 „ both are used.

Of the places which are not sewered there are,—

1 where water-closets are general.
 6 „ privies „ „
 3 „ both are used.

Disposal of Liquid Sewage and Contents of Pits &c.—At 71 places out of the 107 the liquid sewage, consisting either of the discharge from water-closets, or of the drainage and overflow from pits and cesspools, is discharged into the adjoining stream or river, and in two instances it is discharged into pools of water. At a few of those places the sewage is first submitted to some kind of treatment, chiefly with the object of preventing or mitigating nuisance. At Bury St. Edmunds the liquid sewage is partly got rid of by means of dead wells.

In 38 places the contents of pits and cesspools are carted away.

At 15 places the liquid sewage is applied to land, either wholly or partially, and at 2 of those places it is previously subjected to treatment.

The number of towns where these different plans are adopted is shown by the following Table :—

			Sewage discharged into rivers &c.	Sewage used for irrigation.	Contents of pits carted away.
Towns completely sewer- ed	48	Water-closets general	26	3	15
		Privies			
		Both used	2	5	
Towns partially sewer- ed	48	Water-closets general	9	3	18
		Privies	17	2	
		Both used	12		
Towns not sewer- ed	11	Water-closets used			5
		Privies	4		
		Both	1		

Total number 107

It will be evident that, according to local conditions, there will be great differences in the nature of the liquid sewage of different places, and that even the contents of pits, cesspools, &c. will vary, according as the soil is readily or slightly permeable. The amount of the water-supply and the admission or exclusion of surface-water from the sewers will also be of influence in this way.

Total Quantity and Amount of Liquid Sewage.—Among the 96 places where there is a system of sewerage, either general or partial, combined with water-closets and a copious supply of water, the minimum daily quantity of liquid sewage discharged varies from 20,000 gallons as at Alton, to 17 million gallons as at Birmingham, and 130 million gallons as at Liverpool.

The storm-discharge at places where the surface-water is admitted to the sewers varies from one and a half to twenty times as much as the discharge during dry weather, and at places where the surface-water is wholly or partially excluded it varies from one and one-tenth to seven times as much as the dry-weather discharge.

The average amount of liquid sewage per head of the population in places where the surface-water is admitted to the sewers varies from 10 to upwards of 100 gallons, and at places where the surface-water is excluded it varies from 6 to 100.

Treatment of Liquid Sewage.—At 15 of the places which are sewer-
ed wholly or partially, the liquid sewage is subjected to treatment either by allowing it to remain for a time in settling-tanks, from which the deposit is occasionally removed, as at Burton-on-Trent, Birmingham, Epsom, Farnham, and Andover, or by filtering, as at Uxbridge and Ealing.

In eight instances deodorizing materials are added to the sewage. Lime and carbolic acid are used at Carlisle and Harrow, lime alone is used at Leicester, lime and chloride of lime at Luton, perchloride of iron at Cheltenham, perchloride of iron and lime at Northampton, ferruginous clay treated with sulphuric acid at Stroud, and at Leamington the lime treatment has lately been superseded by the method proposed by Messrs. Sillar and Wigner. By this treatment the sewage is clarified, and a deposit is separated which is sold as manure.

In regard to the effects thus produced, it is stated that at Leicester the sewage runs off as pure as ordinary rain-water; at Ealing it is said to be free from smell, colourless, and harmless to vegetable or animal life; at Stroud and Luton the effect is stated to be satisfactory. At Harrow the nuisance is said to be somewhat mitigated, and at Abergavenny the stench is said to be abated by the treatment of the sewage. At Bury St. Edmunds upward filtration through charcoal and gypsum has been abandoned as too costly and in favour of irrigation. At Banbury treatment of the sewage has failed, and irrigation is now resorted to. At Hereford, where it was proposed to be adopted in the Parliamentary plans, it has not been tried, on the score of expense. At Tonbridge it is about to be tried; and at Hastings and Cambridge experiments are being made.

The cost of treatment amounts to £1200 a year at Leicester for a population of 89,000 discharging into the sewers. At Ealing, with a population of 7500, the annual cost is £300, and the cost of the plant for the purpose was £3000. At Luton, with a population of 18,000, the annual cost is £500; at Cheltenham, with a population of 36,000, it is £350; at Uxbridge, with 7000 population, it is £200; and at Alton, with 3300 population, it is £46.

The solid deposit obtained by treating liquid sewage is sold at prices varying from 6*d.* to 2*s.* 6*d.* per ton. At Leicester as much as 5000 tons is produced. At Luton the deposit is mixed with night-soil, at Banbury with street-sweepings, and at Stroud it is made the basis of a manure that is said to be sold at £7 10*s.* per ton.

Application of Liquid Sewage for Irrigation.—In only 15 places out of the 96 where the water-carriage system of removing excretal refuse is adopted, either generally or partially, is the sewage applied for irrigating land. Of these places 8 are completely sewered; in 11 of them water-closets are general, and in 2 they are partial. The remaining 7 towns are only partially sewered, and in 3 of these water-closets are general, while privies are general in the other 4 towns.

The areas of land to which the sewage of these places is applied are shown by the following Table:—

Towns.		Population dis- charging into sewers.	Area of irrigated land.	Area re- quired for irrigation	Character.	Additional land.
Privies general.	Water-closets general.	Completely sewered.	Acres.	Acres.	Various. Pasture. Gravel & clay. Clay. Stiff. [soil. Gravel sub- Pasture.	Some in hands of lessee. [reach. 150 acres, too high to 90 " None " 14 "
			336	.....		
			110	110		
			65	50		
			50	50		
			30	100		
			15	.....		
			120	134		
			55	.....		
			40 to 50	.....		
	Partially sewered.	Completely sewered.			[gravel. Clay and Clay subsoil. Light.	100 " 46 "
						
						
						
						
						
						
						
	Partially sewered.	Completely sewered.	.....	.....		
						
						
						
						
						
						
						

The following towns are about to apply their sewage for irrigation, or they contemplate doing so:—

Towns.		Population dis- charging into rivers.	Area of land to be irrigated.	Character.	Additional land.
W.C. general.	{ Tunbridge Wells ...	12,800	Acres. 123	.....	170 acres.
	{ Surbiton	7,100			
	{ Kingston-on-Thames	12,000			
	{ Nottingham.....	86,000			
	Inverness.....	18,000 ?	.....	Light loam.	
	Perth	16,000	.....	Sandy.	
	Aberdeen	60,000			
	Norwich	57,000	700	Light.	500 „
	Skipton	5,500			
	Reigate	9,000			
Aylesbury					
Evesham					

At Tonbridge it is stated that the application of the sewage for irrigating land would be almost impossible, and the local authorities believe all trials that have been made to apply sewage in this way are failures and a source of dissatisfaction on account of nuisance and expense. Lincoln is also said not to admit of this application of sewage. At Cambridge the subject is under consideration.

Comparing the extent of land irrigated and the population discharging into the sewers at the places above named, it appears that in the case of Birmingham there is only $\frac{1}{4}$ of an acre per 1000 of population; at Edinburgh there is 1.7 acre per 1000; at Carlisle, Bedford, and Chorley there is from 3 to 3.5 acres; at Harrow, Reigate, and Chelmsford there is from 5 to 6.6 acres; at Epsom, Rugby, and Malvern from 7.5 to 10 acres; at Tunbridge Wells, Banbury, and Norwich from 10 to 12 acres per 1000.

There does not appear to be any provision in most cases for additional land for irrigation except at Carlisle and Norwich. At Chelmsford there is some, but it is too high to be reached; and at Tunbridge Wells the purchase of additional land is contemplated.

At Carlisle, Reigate, Epsom, Inverness, and Tenterden the land selected for irrigation is situated within the district, under control of the local sewer authorities, at a distance of from one-fifth of a mile to half a mile from the centre of the town, and within a quarter of a mile of the outskirts. At Edinburgh, Bedford, Rugby, Chelmsford, Harrow, Skipton, Norwich, Perth, and Bury St. Edmunds, it is outside the district, at a distance of from half a mile (Perth) to 3 miles (Norwich) from the centre of the town, and from half a mile (Bury St. Edmunds, Harrow, Chelmsford, Bedford) to $\frac{1}{2}$ mile (Norwich) beyond the outskirts; at Birmingham, Chorley, Braintree, Banbury, and Malvern the land is partly within and partly outside the district under the sewer authorities.

The distance of the irrigated land from the lowest sewer-outlet of the town varies from 100 yards to upwards of a mile. In some cases it has been purchased, as at Harrow, Reigate, and Tunbridge Wells; but in most cases it has been leased. Sometimes it is occupied by the sewer authorities, sometimes let to a farmer, as shown in the accompanying Table, which shows also the cost of delivery to the land by gravitation or pumping, and other details.

At most places the application of the sewage to land has been found to exercise a most beneficial influence on the condition of the streams and rivers receiving the drainage of the district. At Epsom there was some damage done to the Hog's Mill River, but no complaint is now made. Even where only the solid portion of the sewage is separated by filtration or precipitation, the state of rivers receiving the discharge is to some extent improved. At Northampton an application for an injunction has been made by a miller resident on the stream.

Generally speaking no objections appear to have been made to the application of sewage for irrigation; and where such objections have been urged, on the ground that the application was offensive and injurious, they do not appear to have been supported by medical authority, and in several instances they have ceased.

As regards the sanitary condition of these districts, it appears that in most cases the application of sewage for irrigation has not been attended with any apparent change; but there is said to be a marked improvement at Braintree.

It is to be understood that, in all cases, the data given in this Report and relating to this country, have been obtained from the local sewer authorities, in reply to letters of inquiry sent by the Committee, and that since there has

Situation of irrigated land relatively to the district under control of the sewer authorities.	Name of town.	Distance of irrigated land			Irrigated land has been		Occupation of the irrigated land		Sewage applied to land	
		from the town		from the lowest sewer outlet.	Leased.	Bought.	by the sewer authorities.	let to farmers.	by gravitation.	pumped.
		centre.	outskirts.							
Without.....	Edinburgh.....	mile	mile	.....	.....	.....	.....	*	*	.....
	Bedford.....	1	$\frac{1}{2}$	$\frac{1}{2}$	*	.....	*	.....	.....	*
	Rugby.....	1 $\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	*	.....	*	.....	*	.....
	Chelmsford.....	1	$\frac{1}{2}$	$\frac{3}{4}$	.....	.....	.....	*	.....	*
	Harrow.....	1 $\frac{1}{2}$	$\frac{1}{2}$	.....	.....	*	*	.....	*	.....
	Skipton.....	.....	.....	.....	.....	.....	.....	*	*	.....
	Norwich.....	3	1 $\frac{1}{2}$	1 $\frac{1}{2}$	*	.....	not decided	.....	.....	*
	Perth.....	$\frac{1}{2}$	500 yds.	150 yds.	.....	.....	.....	.....	.....	*
	Bury St. Edmunds.....	1	$\frac{1}{2}$	100	*	.....	.....	*	*	*
	Birmingham.....	2 $\frac{1}{4}$	$\frac{1}{2}$	.....	*	.....	*	.....	*	*
Partly within.....	Chorley.....	1	$\frac{3}{4}$	600	*	.....	*	.....	*	.....
	Braintree.....	$\frac{1}{2}$	.....	$\frac{1}{2}$	.....	.....	.....	*	.....	.....
	Banbury.....	.....	.....	$\frac{1}{2}$	*	.....	*	.....	*	*
	Malvern.....	1	$\frac{1}{2}$	$\frac{1}{2}$	.....	.....	*	.....	*	.....
	Carlisle.....	$\frac{1}{2}$	.....	.....	*	.....	.....	*	.....	*
Within.....	Reigate.....	.....	.....	.....	.....	*	.....	.....	.....	.....
	Epsom.....	$\frac{1}{2}$	$\frac{1}{2}$	.....	*	.....	.....	.....	*	*
	Inverness.....	1	.....	.....	.....	.....	.....	partly	.....	.....
	Tentarden.....	.....	.....	$\frac{1}{2}$	.....	.....	.....	*	*	.....



not yet been any opportunity for examining in detail the circumstances of any particular locality, it would be premature at present to venture on any conclusions as to the numerous questions arising in reference to the treatment and utilization of sewage, or even to trust implicitly to the figures &c. given. Even on the assumption that the information furnished to the Committee does fairly represent the whole of the circumstances to be considered, that information presents so much variation and even discrepancy in several important details, that it seems indispensable there should be, in many instances, a minute investigation upon the spot, which the Committee has not yet had the power to make.

Although the Committee regards the present Report as dealing only partially with the subject of sewage, and as being in fact only a preliminary step towards the work required to be done, it is considered that there are two points (*viz.* the cost of various methods of dealing with excretal refuse, and their influence on the sanitary condition of towns) which must be referred to here, so far as the data obtained will permit.

The removal of the contents of pits and cesspools by cartage appears to be in some few instances conducted with some profit; more frequently, however, the cost is at least equal to the return obtained, and very often it is a source of loss. In regard to this point there is a marked difference between the results obtained in this country and those obtained on the Continent, where the removal of the contents of the pits is frequently profitable, either to individuals or to towns. The treatment of liquid sewage does not appear to have been advantageous in any instance, except in lessening the nuisance that would otherwise be caused by the discharge of sewage into rivers, and in most instances it has been a source of loss to the towns where it is practised.

The cost of the application of sewage for irrigating land appears to be dependent on a number of local conditions, and consequently to vary considerably. It would seem, from the data obtained, that in many instances the outlay requisite for this purpose would exceed what a farmer could be expected to incur, and that, in such cases at least, it would be proper to regard this outlay as coming under two distinct heads, *viz.* that which a town may reasonably be expected to bear for the mere object of getting rid of its refuse, and that which landowners or farmers may be able to incur for the improvement of their land. It is probable that, when viewed in this light, the application of liquid sewage to land would become a source of revenue to towns only under specially favourable circumstances; and that, in opposition to the opinions which have been somewhat hastily formed in certain cases, it will more frequently entail some amount of expenditure on the towns themselves. At the same time the benefit to land, and the improvement in the condition of rivers to be realized by the mode of dealing with liquid sewage, can scarcely be matter of doubt or uncertainty any longer.

In regard to the sanitary aspect of the subject, it may be regarded as beyond question that the practice of allowing excretal refuse to accumulate and remain neglected for a long time near dwellings, in pits, middens, cesspools, or otherwise, is almost invariably accompanied by prejudicial effects on the sanitary condition of the places where it is adopted, either by the impregnation of the soil with decaying material, by the pollution of water, or by noxious exhalations.

But even in some places where the water-supply has been improved, where a system of sewerage has been adopted, and other measures have been taken with the object of getting rid of excretal refuse, the fact that the rate of mortality has not been sensibly, if at all diminished, appears to point to some circumstance, as yet insufficiently guarded against, which still exercises a pre-

judicial influence. The imperfect or defective nature of the sewerage may, by allowing infiltration of sewage into the soil and its passage to the foundations of houses, in some cases be the cause to which this result is referable. But one part of the sewerage system which most urgently demands attention at the present time is the ventilation. Gases of a poisonous or deleterious nature are freely given off from liquid sewage in its passage along the sewers, or from deposits collecting in them and in the house-drains. These gases naturally ascend the sewers, and find egress, either into the streets of a town or into the dwellings, by means of the house-drains and otherwise. The means adopted for getting rid of these gases, without injury to the sanitary state of a town or of the houses in it, are rarely of such a kind as to be effective; and the returns already obtained in reference to this matter sufficiently show that attention has not been directed to it in a degree commensurate with its importance.

On these grounds the Committee considers that it would be in the highest degree desirable to institute an inquiry into the nature of the gaseous emanations from sewers in various places, that being one of the points now most important in connexion with the system of disposing of excreta refuse which is rapidly being adopted throughout this country. In reference to the application of liquid sewage to land, it is also considered that, in addition to various other points relating to the application and purification of sewage-water by irrigation, it would be very serviceable to make some inquiry into the nature of the sewage discharged in various places, so as to ascertain the differences that exist in liquid sewage so far as its value as manure is concerned, and at the same time to endeavour to obtain more definite information as to the cost of removing night-soil, and as to its agricultural value as established by practice.

Supplement to the Second Report of the Committee on the Condensation and Analysis of Tables of Steamship Performance.

THE Committee have to report that the sum of £30 granted to them has been wholly expended in the payment of Mr. Quant, their calculator, as authorized in the resolution by which they were appointed. The calculator's time was employed partly in revising the printed Tables, which appeared in the volume of Reports for 1868, and partly in making an additional analyzed Table. The last-mentioned Table in MS. was delivered to the Secretary of the British Association early in the present year, and is annexed hereto. The Committee beg leave to represent that it is desirable that they should be reappointed, for the purpose of superintending the printing of that Table; but that no further grant of money will be required. They have again to express their satisfaction with the manner in which Mr. Quant performed his duties.

Revised Analysis, according to the method of Mr. Scott Russell.

In the Table of analyzation according to Mr. Scott Russell's method, as originally computed, the length of forebody was assumed at $\cdot 55$ of the length of the ship, which in practice is generally the place of the midship section. This length of bow belongs to the displacement of the ship, but not to the speed. Therefore in calculating the resistance there are introduced a coefficient of diminished resistance belonging to one bow and a speed belonging to another bow, or, in other words, two ships have been used.

In the following Table this has been rectified by taking a length of bow belonging to the speed and also to the displacement. For example, the speed of a ship is 11·22 knots, or 18·96 feet per second; to this belongs a bow of 70 feet, and an afterbody of 47 feet; the ship is 336 feet long, hence there remains for middlebody 219 feet. Now the question arises, what is the corresponding area of midship section? because if the area of midship section as given in the Tables were used, it would result in too large a displacement with the above dimensions of fore, after, and middlebody. For this purpose we have as follows:—

$$\text{Area of midship section} \times (\cdot 5l + \cdot 5l' + l'' + \cdot 19635 B) = D \times 35.$$

Substituting $l=70$, $l'=47$, $l''=219$, $B=40\cdot92$, and $D=3979$, the result is an area of midship section $=487\cdot7$ square feet. By the Tables it is given as 653; and the calculated section is therefore 165·6 $\square'$ too small, or the vessel under the above dimensions sits lighter on the water. It is the lighter midship section which has been used in the following Table. To find the corresponding draught, taking the sides of the ship at the midship section as nearly vertical, the difference is divided by the beam of the ship and the quotient subtracted from the given draught. This results in a lighter draught of 14·3 feet instead of 18·35 as given by the Table—a difference of 4·04 feet. The difference is not always so large; in some vessels it does not amount to a foot.

Twice this difference in draught has been deducted from the actual girth of the midship section in order to find a girth suited for calculating the wetted surface; in the example this gives $G=54\cdot72$ instead of 62·8.

The coefficient of diminished resistance has been taken to belong to the bow as assumed above, and has been calculated by taking the square of the sine of the angle formed by half the beam and the length.

The skin has been calculated by the following formula,

$$(\cdot 58G + \cdot 84d)(l + l') + l''G = \text{skin or wetted surface},$$

in which formula the lighter girth at the midship section and the lighter draught must be substituted.

The calculations of resistance due to ship's way, skin, &c. have been made in the manner explained in the second Report. It may happen that the length of bow belonging to speed is greater than the ship itself as given in the Tables, as in the case of the 'Midge' and 'Penelope.' In such cases an afterbody is added to the forebody belonging to that speed, and with the two lengths and the given displacement the area of midship section, draught, and girth have been calculated.

It will be seen that in the following revised Table most of the negative quantities which appeared in the former Table have disappeared. The quantities in the following Table belong to ships of the same displacement, same speed, same length, same beam, and same indicated horse-power with the actual ships; whilst those in the former Table belong to ships of the same displacement, same length, same breadth, same draught, and same indicated power, but not the same speed, although that speed was introduced in the calculations resulting for the most part in the negative quantities as found for slip or engines.

Revised Table of Analysis, according

	Atrato (paddle).	Tasmanian (screw).	Valparaiso (paddle).	Leonidas (screw).	Pera (screw).	Ceylon (screw).
Speed of ship, in knots per hour	11'22	14'25	11'53	11'7	12'556	13'34
Speed of ship, in feet per second	18'96	24'08	19'48	19'77	21'22	22'54
Length of bow belong- ing to speed, in feet	70'	116'	76'	76'	89'5	101'16
Length of stern, in feet	47'	73'	51'	51'	59'6	67'44
Length of middlebody, in feet	219'	138'	105'	76'	151'	131'40
Total length of ship as calculated, in feet	336'	332'	232'	203'	300'1	300'
Total length of ship as actual, in feet	336'	332'	232'	203'	300'	300'
Breadth of ship, in feet	40'92	39'	29'	29'12	42'08	41'
Area of midship section, as belonging to cal- culated ship	487'7	500'	246'	195'	414'	460'
Area of midship section, actual	653'	577'	308'	207'	592'	582'
Displacement, in cubic ft.	139265'	118125'	42700'	28350'	104020'	102900'
Draught of water be- longing to calculated ship D	14'31	17'08	9'53	7'34	14'74	14'37
Draught of water, actual	18'35	19'08	11'67	7'75	18'25	18'25
Slip, in feet per second	5'19	4'92	9'22	3'7	1'53	1'98
Coefficient of dimi- nished resistance	'0786	'0274	'0351	'0353	'0524	'0394
Indicated horse-power	2207'98	2800'	800'	340'	1414'	2040'
Girth, corresponding to lighter draft D....	54'72	57'72	36'54	33'53	51'	57'
Skin or wet surface, in square feet	17102'	17240'	6772'	5799'	13957'	15124'
Resistance due to ship's way, in pounds	13783'	7952'	3277'	2692'	10476'	9209'
Resistance due to skin, in pounds	21530'	35008'	9002'	7938'	22003'	26914'
Total resistance, in lbs.	35313'	42960'	12279'	10630'	32479'	36123'
Horse-power required for ship's way	299'	348'	116'	96'7	404'	377'
Horse-power required for skin	742'	1532'	318'8	285'	850'	1103'
Horse-power required for ship	333'	384'	206'	71'	90'	130'
Horse-power required for engines and pro- peller	833'	536'	160'	.....	70'	430'
Percentage of total horse-power required for ship's way	13'	12'4	14'5	21'	28'	18'
Percentage of total horse-power required for skin	'33	54'7	39'8	80'	60'	54'
Percentage of total horse-power required for ship	15'	13'7	25'7	19'	6'5	6'
Percentage of total horse-power required for engines and pro- peller	37'	19'	20'	.....	5'	21'

to Mr. Scott Russell's Method.

San Carlos (screw).	Guayaquil (screw).	Delta (paddle).	Lancefield (screw).	Undine (screw).	Penelope (screw).	Midge (screw).	Leinster (paddle).
11'75	12'	14'67	9'6	9'26	10'85	10'53	16'28
19'85	20'28	24'79	16'22	15'64	18'33	17'79	27'51
77'	82'	122'	53'	47'5	67'	63'5	148'
55'	55'	81'	35'	34'	44'	42'	99'
60'	58'	105'	56'67	43'5	.....	.....	80'
192'	195'	308'	144'67	125'	111'	105'5	327'
192'	195'	308'	145'	125'	74'33	58'75	327'
30'	30'	35'25	23'	25'	12'75	12'67	35'
185'76	222'	377'	119'28	115'42	28'	24'	302'
260'	260'	400'	157'	154'3	32'	40'	330'
24500'	29400'	80500'	12565'	10290'	1627'	1575'	63525'
8'45	10'	14'17	7'	{ 7'69 without keel. }	3'77	2'84	12'57
11'83	11'71	15'	8'	{ 7'66 without keel. }	4'08	4'	13'37
9'19	9'52	4'	6'18	3'29	7'17	6'21	5'71
'0365	'0334	'0204	'0471	'0648	'0089	'0099	'0137
500'	600'	1624'	200'	157'09	93'	100'	4160'
35'	38'26	50'34	30'	{ 32'84 without keel. }	15'48	13'6	42'9
5715'	6409'	13626'	3748'	{ 4106'79 with keel. }	1346'43	1083'8	12185'
2672'	2956'	4732'	1408'	1830'	84'34	75'6	3142'
7890'	9228'	29324'	3468'	3521'	1585'	1201'	32290'
10562'	12184'	34056'	4876'	5351'	1669'34	1276'6	35432'
96'5	109'	213'	41'5	52'	2'81	2'45	157'
284'7	340'	1321'	102'2	100'	52'82	38'8	1615'
.....	11'	247'	54'	32'	21'7	14'4	368'
119'	140'	.....	2'7	.....	15'67	46'65	2020'
19'	18'	12'	20'	28'	3'	2'5	3'8
56'	56'	74'	51'	54'	56'	38'	38'
.....	2'	14'	27'	17'	23'	14'5	8'8
23'	23'	.....	1'3	...	17'	45'5	50'

Report on Recent Progress in Elliptic and Hyperelliptic Functions.

By W. H. L. RUSSELL, F.R.S.

I SHALL never forget the evening when I first became acquainted with Mr. Ellis's report on the present state of Analysis published by this Association. I felt like a traveller who, on entering an unknown country through dark and narrow paths, suddenly arrives at an eminence from which he sees the whole region spread out like a map before him, and perceives at a glance the roads leading to the principal cities, and the most desirable mansions. I followed this guidance in my reading, and, as I proceeded, became anxious to attempt for others what Mr. Ellis had effected for me, and in consequence to undertake the present Report.

I shall keep steadily in view three main objects. In the first place, I shall endeavour to prove theorems enunciated by their authors without demonstration. Secondly, to explain passages which may present difficulties, and to give such directions as may enable the reader to arrive with the least difficulty at the most important parts of the different memoirs which will come under review. And, thirdly, to give such a connected view of the whole, as will enable anyone entering on the study of our present subject to know beforehand the nature of the results which have been obtained.

Elliptic functions will first be considered; and I shall divide the subject into four parts.

(1) I shall consider recent researches in this branch which do not involve the idea of periodicity.

(2) Recent investigations relative to function Θ , and its allied series.

(3) Modular equations, and some other researches of a similar description.

(4) Some of the most important geometrical and physical applications of elliptic functions.

PART I.

Section 1.—It will be proper to commence by giving a list of the principal algebraical integrals which can be reduced to elliptic functions. They are taken from Schellbach's 'Lehre von den Elliptischen Integralen,' and from a paper by Rötting in the fifty-sixth volume of Crelle's Journal. Along with the integrals I shall indicate the transformations necessary for their reduction.

$$\int \frac{dx R(x)}{\sqrt{a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6 \dots}} \quad (1)$$

Let $z = x + \frac{1}{x}$. I know not if it has ever been remarked that the same substitution will enable us to integrate $\int \frac{dx R(x)}{\sqrt{a + bx + cx^2 + bx^2 + ax^4}}$ in logarithms or circular arcs.

Hence we can reduce to elliptic functions

$$\int \frac{dx R(x^2)}{\sqrt{a_0 + a_1 x^2 + a_2 x^4 + a_3 x^6 + a_4 x^8 \dots}} \quad (2)$$

by putting $x^2 = z$, to which can be reduced

$$\int \frac{dx R(x)}{\sqrt{a_0 + a_1 x^2 + a_2 x^4 + a_3 x^6 + a_4 x^8}}, \dots \dots \dots (3)$$

since $Rx = R_1 x^2 + x R_2 x^2$.

We can also reduce

$$\int \frac{dx}{\sqrt{a + bx^4 + cx^8}} \dots \dots \dots (4)$$

by putting $cx^8 = az^8$.

So also

$$\int \frac{dx R(x^2)}{\sqrt{a + bx^2 + ex^4 + cx^6}} \dots \dots \dots (5)$$

by putting $x^2 = z$, to which can be reduced

$$\int \frac{dx R(x)}{\sqrt{a + bx^2 + cx^3 + ex^6}} \dots \dots \dots (6)$$

since $R(x) = R_1 x^2 + x R_2 x^2$.

We are also able to express

$$\int \frac{dx R(x)}{\sqrt[3]{ax + bx^2 + cx^3}} \dots \dots \dots (7)$$

by elliptic functions, if we put $xz = \sqrt[3]{ax + bx + cx^3}$, to which can be reduced

$$\int \frac{dx R(x)}{\sqrt[3]{a + bx + cx^2 + ex^3}} \dots \dots \dots (8)$$

by putting $x = y + p$, where $a + bp + cp^2 + ep^3 = 0$.

Again, we can reduce

$$\int \frac{dx R(x^2)}{\sqrt[4]{a + bx^2 + cx^4}} \dots \dots \dots (9)$$

to elliptic functions, if we make $x^2 z^2 = a + bx^2 + cx^4$; and also

$$\int \frac{dx x R(x^2)}{\sqrt[4]{a + bx + cx^2}} \dots \dots \dots (10)$$

if we make $z = \sqrt[4]{a + bx + cx^2}$.

Moreover

$$\int \frac{dx R(x)}{\sqrt[4]{a + bx^3 + cx^6}} \dots \dots \dots (11)$$

can be reduced to the two last cases, since

$$R(x) = R_1 x^2 + x R_2 x^2.$$

Lastly, the more general integral

$$\int \frac{dx \cdot R(x)}{\sqrt[4]{a + bx + cx^2 + ex^3 + hx^4}} \dots \dots \dots (12)$$

can be reduced to (11) by putting $x = \frac{\alpha + \beta z}{\gamma + z}$, and proceeding as in elliptic functions.

Section 2.—In the eighth volume of the ‘Cambridge and Dublin Mathematical Journal’ there is a paper by Mr. F. Newman “On the Third Elliptic Integral.” The principal object of this paper is to apply Lagrange’s transformation to this integral so as to obtain available results. The interest and difficulty attaching to this are great, and I think it well, therefore, to present Mr. Newman’s leading theorem to the reader in a form which he will find it easy to follow.

Let

$$\Delta_1 = \sqrt{1 - c_1^2 \sin^2 \theta_1}, \quad \Delta = \sqrt{1 - c^2 \sin^2 \theta},$$

$$\Pi(c, n, \theta) = \int \frac{d\theta}{(1 + n \sin^2 \theta) \Delta},$$

$$\Gamma(c, n, \theta) = \Pi(c, n, \theta) - \frac{F(c, \theta)}{F(c)} \Pi(c, n).$$

Then, following the usual scale of Lagrange, if

$$\sin \theta_1 = (1 + c') \frac{\sin \theta \cos \theta}{\Delta}, \quad c' = \sqrt{1 - c^2}, \quad c_1 = \frac{1 - c'}{1 + c'},$$

we have

$$\int \frac{d\theta_1}{(1 + n_1 \sin^2 \theta_1) \Delta_1} = (1 + c') \int \frac{\Delta d\theta}{\Delta^2 + n_1 (1 + c')^2 \sin^2 \theta \cos^2 \theta} \dots \quad (1)$$

Let us assume

$$\Delta^2 + n_1 (1 + c') \sin^2 \theta \cos^2 \theta = (1 + n \sin^2 \theta)(1 - m \sin^2 \theta),$$

where m and $-n$ are two new parameters. Then

$$nm = n_1 (1 + c')^2, \quad (1 + n)(1 - m) = c'^2, \quad \dots \quad (2)$$

$$\left. \begin{aligned} \sqrt{\left\{ (1 + n_1) \left(1 + \frac{c_1^2}{n_1} \right) \right\}} &= \frac{n + m}{(1 + c') \sqrt{nm}}; \\ \sqrt{\left\{ (1 + n) \left(1 + \frac{c^2}{n} \right) \right\}} &= \frac{(1 + n) \sqrt{nm}}{n}; \end{aligned} \right\} \dots \quad (3)$$

whence, since remembering the second of equations (2),

$$\frac{\Delta}{(1 + n \sin^2 \theta)(1 - m \sin^2 \theta)} = \frac{nm}{m + n} \left\{ \frac{1 + n}{n} \cdot \frac{1}{(1 + n \sin^2 \theta) \Delta} + \frac{1 - m}{m} \cdot \frac{1}{(1 - m \sin^2 \theta) \Delta} \right\}.$$

Therefore from (1),

$$\Pi(c_1, n_1, \theta_1) = (1 + c') \frac{mn}{m + n} \left\{ \frac{1 + n}{n} \Pi(c, n, \theta) + \frac{1 - m}{m} \Pi(c, -m, \theta) \right\},$$

putting $\theta = \frac{\pi}{2}$, and therefore $\theta_1 = \pi$,

$$2\Pi(c_1, n_1) = (1 + c') \frac{mn}{m + n} \left\{ \frac{1 + n}{n} \Pi(c, n) + \frac{1 - m}{m} \Pi(c, -m) \right\}.$$

Multiply this by $\frac{1}{2} \frac{F(c, \theta_1)}{F(c)} = \frac{F(c, \theta)}{F(c)}$, and subtract from the last equation, and we have by definition

$$P(c, n, \theta_1) = (1+c') \frac{mn}{m+n} \left\{ \frac{1+n}{n} P(c, n, \theta) + \frac{1-m}{m} P(c, -m, \theta) \right\}. \quad (4)$$

But (Hymers's 'Integral Calculus,' p. 284)

$$\begin{aligned} \frac{1+n}{n} \Pi(c, n, \theta) - \frac{1-m}{m} \Pi(c, -m, \theta) &= \frac{c^2}{m} F(c, \theta) \\ &+ \frac{1}{\sqrt{mn}} \tan^{-1} \left\{ \frac{\sqrt{mn} \sin \theta \cos \theta}{\Delta} \right\}. \end{aligned}$$

From this we obtain

$$\frac{1+n}{n} P(c, n, \theta) - \frac{1-m}{m} P(c, -m, \theta) = \frac{1}{\sqrt{mn}} \tan^{-1}(\sqrt{n_1} \sin \theta_1); \quad (5)$$

therefore we have from (4) and (5), remembering (2),

$$\begin{aligned} \sqrt{\left\{ (1+n) \left(1 + \frac{c^2}{n} \right) \right\}} P(c, n, \theta) &= \frac{1}{2} \sqrt{\left\{ (1+n_1) \left(1 + \frac{c^2}{n_1^2} \right) \right\}} P(c, n_1, \theta_1) \\ &+ \frac{1}{2} \tan^{-1}(\sqrt{n_1} \sin \theta_1); \end{aligned}$$

whence it is easy to see that if θ_2 and n_2 &c. are formed from θ_1 and n_1 as θ_1 and n_1 were formed from θ and n , we have

$$\begin{aligned} \sqrt{\left\{ (1+n) \left(1 + \frac{c^2}{n} \right) \right\}} P(cn\theta) &= \frac{1}{2} \tan^{-1}(\sqrt{n_1} \sin \theta_1) \\ &+ \frac{1}{4} \tan^{-1}(\sqrt{n_2} \sin \theta_2) + \frac{1}{8} \tan^{-1}(\sqrt{n_3} \sin \theta_3) + \dots \end{aligned}$$

This very beautiful theorem applies to the third elliptic integral with circular parameters; but it is obvious that it may be easily extended to logarithmic parameters, as has been done by Mr. Newman. In a subsequent part of his paper, Mr. Newman points out the connexion between his own researches and some of Jacobi's discoveries.

Section 3.—In the 36th volume of Crelle's Journal there is a Memoir by the late Professor Plana, of Turin, on the reduction of $\int \frac{T dx}{\sqrt{X}}$, to elliptic functions, where

$$T = G + G'x + G''x^2 + \frac{H + H'\sqrt{-1}}{1 + (K + K'\sqrt{-1})x} + \frac{H - H'\sqrt{-1}}{1 - (K - K'\sqrt{-1})x}$$

and

$$X = x^4 + \lambda x^3 + Ax^2 + Bx + C.$$

It would be impossible to give an analysis of this memoir without reproducing it, which is the less necessary as so much has been written on this subject. I shall therefore confine myself to directing the reader's attention to a particular portion of it.

At the beginning of the ninth section there is a method for reducing the sums of two elliptic functions of the form

$$2 \int \frac{dy}{(1-fy^2)\sqrt{Y}} \quad 2 \int \frac{dy}{(1-f'y'^2)\sqrt{Y'}}$$

where $f=g+h\sqrt{-1}$, $f'=g-h\sqrt{-1}$,

$$Y=(M+N\sqrt{-1})(P+Q\sqrt{-1})$$

to the sum of two of the form

$$\int (1+n'y^2)\sqrt{Y} \cdot \int (1+n''y^2)\sqrt{Y}$$

where n' and n'' are real. The method is founded on substituting

$$y=\frac{\eta(1+\xi\eta')}{\sqrt{Y}} \text{ in } \int \frac{d\eta}{1+\eta'^2}$$

and then finding two suitable values for ξ . The section to which I refer is almost detached from the rest of the memoir, and may be read without difficulty. There is another paper by Richelot on this subject in the 34th volume of Crelle's Journal.

Section 4.—Of late the theory of continued fractions has received a very wide extension. A very beautiful example of this will be found in the 56th volume of Crelle's Journal, in which Laplace's coefficients are applied to the expansion of functions in continued fractions. It is not, therefore, surprising that the expansion of elliptic functions in this manner should have been the subject of several successful efforts. In the 39th volume of Crelle's Journal there is a paper on this subject by Professor Malmsten. The known equations

$$k\frac{dW'}{dk}=W'-W'', \quad k k' \frac{dW'}{dk}=W'-k'^2 W'' \quad . \quad . \quad . \quad (1)$$

easily lead to the differential equation

$$(y^2-2k'^2y+k'^2)dk+k k'^2 dy=0 \quad . \quad . \quad . \quad (2)$$

$$\text{where } y=\frac{W'k}{W''k'}.$$

If we put

$$k=\left\{m\alpha+\frac{1+c}{2}\right\}^{\frac{1}{2}} \quad y=\frac{1}{2}(1-c-2m\alpha)+\frac{1-(c+2m\alpha)^2}{2m}u \quad . \quad . \quad (3)$$

this last equation may be written

$$(m^2x^2+mcx+\frac{1}{4}(c^2-1))\left(\frac{du}{dx}+u^2\right)+mu(2m\alpha+c)+\frac{1}{4}m^2=0 \quad . \quad . \quad (4)$$

But from (3),

$$\frac{W'k}{W''k'}=k'^2+2k'^2k'^2\cdot\frac{u}{m}.$$

Therefore by the second of equations (1),

$$2k'^2k'^2\frac{u}{m}=\frac{k k'^2 \frac{dW'}{dk}}{W''}$$

or

$$u=\frac{m}{2k'}\cdot\frac{\frac{dW'}{dk}}{W''}=\frac{dk'}{dx}\cdot\frac{\frac{dW'}{dk}}{W''}=\frac{dx}{W''}.$$

* I have been fuller here because several steps are omitted by Malmsten.

Hence if $z = F' \left(mx + \frac{1+c}{2} \right)^{\frac{1}{2}}$, $u = \frac{z'}{z}$, the equation (4) becomes

$$\left(m^2 x^2 + max + \frac{c^2 - 1}{4} \right) z'' + m(2mx + c)z' + \frac{m^2}{4} z = 0.$$

Therefore, differentiating $(n-1)$ times, we have

$$\left(mx^2 + mcx + \frac{c^2 - 1}{4} \right) z^{(n+1)} + mn(2mx + c)z^{(n)} + \frac{(2n-1)^2 m^2}{4} z^{(n-1)} = 0;$$

from this we have

$$\frac{z^{(n)}}{z^{(n-1)}} = \frac{-\frac{(2n-1)^2 m}{4(2mx+c)}}{n + \frac{m^2 x^2 + mcx + \frac{c^2 - 1}{4}}{2m^2 x + mc}} \cdot \frac{z^{(n+1)}}{z^{(n)}}$$

an expression which of course leads to the development of (u) in a continued fraction.

From this Malmsten obtains several results. A very elegant consequence of this investigation is the following theorem:—

Let

$$k = \sqrt{\left\{ \frac{\sqrt{1+x^2}-1}{2\sqrt{1+x^2}} \right\}};$$

then

$$\begin{aligned} & (1-2k^2) \left\{ \frac{E'k}{F'k} - \frac{1-k^2}{1-2k^2} \right\} \\ &= \frac{x}{2+} - \frac{3 \cdot 3 \cdot x^2}{4+} + \frac{5 \cdot 5 \cdot x^2}{6+} - \frac{7 \cdot 7 \cdot x^2}{8+} + \frac{9 \cdot 9 \cdot x^2}{10+}, \end{aligned}$$

which, with several others, will be found fully demonstrated in the paper.

PART II.

Section 1.—In entering on investigations relative to function θ , it is proper to observe that two distinct notations are used to express the same four series. It is now usual to write

$$\theta x = 1 - 2q \cos 2x + 2q^4 \cos 4x - 2q^9 \cos 6x + \dots$$

$$\theta_1 x = 2q^{\frac{1}{4}} \sin x - 2q^{\frac{9}{4}} \sin 3x + 2q^{\frac{25}{4}} \sin 5x \dots$$

$$\theta_2 x = 2q^{\frac{1}{4}} \cos x + 2q^{\frac{9}{4}} \cos 3x + 2q^{\frac{25}{4}} \cos 5x$$

$$\theta_3 x = 1 + 2q \cos 2x + 2q^4 \cos 4x + 2q^9 \cos 6x + \dots$$

These four series are written in 'Fundamenta Nova'

$$\Theta \frac{2Kx}{\pi}, H \frac{2Kx}{\pi}, H \frac{2K}{\pi} \left(x + \frac{\pi}{2} \right), \Theta \frac{2K}{\pi} \left(x + \frac{\pi}{2} \right).$$

The former notation is obviously more convenient; and as uniformity is most desirable, I shall usually adhere to it. It will, however, be occasionally necessary to make use of the second, as it is employed in Crelle's Journal in many papers which I shall have to bring before the reader.

Section 2.—It will be proper, on every account, to commence this division with an account of Jacobi's later researches relative to function Θ . Three of these are contained in the 36th volume of Crelle's Journal, and I shall consider them in succession. The first of these is entitled "Ueber die unmittelbare Verification einer Fundamental-Formel der Theorie der elliptischen Functionen."

It is proved in the 'Fundamenta Nova' that if

$$S = 1 - q(z + z^{-1}) + q^4(z^2 + z^{-2}) - q^9(z^3 + z^{-3}) + \dots$$

$$\Pi = (1 - q^2)(1 - q^2) \dots (1 - q^2)(1 - q^2) \dots (1 - qz^{-1})(1 - qz^{-1}) \dots$$

S and Π are equal, and we must therefore have

$$\frac{dS}{dq} = S \frac{d \log \Pi}{dq}, \quad \frac{dS}{dz} = S \frac{d \log \Pi}{dz}.$$

It appears, without much difficulty, that if (m) represent every whole number from 1 to ∞ , $\psi(m)$ the sum of the factors of (m) , p all odd numbers from 1 to infinity, i all whole numbers from $-\infty$ to $+\infty$, these equations lead to the following:

$$-i^2 = 2\Sigma \psi(m) q^{2m} + \Sigma \Sigma (-1)^m p q^{m(m+p-2i)} + \Sigma \Sigma (-1)^m p q^{m(m+p+2i)}$$

$$-i = \Sigma \Sigma (-1)^m q^{m(m+p-2i)} - \Sigma \Sigma (-1)^m q^{m(m+p+2i)},$$

where $\Sigma \Sigma$ refer to m and p as above explained. The object of the paper is to prove these formulæ, and I make the two following observations to facilitate its study.

The first observation, in which Σ refers to p , is intended to illustrate page 77.

$$\begin{aligned} & \Sigma_1^{\infty} (-1)^m p q^{m(m+p-2i)} + \Sigma_1^{\infty} (-1)^m p q^{m(m+p+2i)} \\ &= \Sigma_1^{4i-1} (-1)^m p q^{m(m+p-2i)} + \Sigma_{4i+1}^{\infty} (-1)^m p q^{m(m+p-2i)} + \Sigma_1^{\infty} (-1)^m p q^{m(m+p+2i)} \\ &= \Sigma_{-(2i-1)}^{2i-1} (-1)^m (2i+\pi) q^{m(m+\pi)} + \Sigma_1^{\infty} (-1)^m (4i+2p) p q^{m(m+p+2i)} \\ & \quad + \Sigma_1^{\infty} (-1)^m p q^{m(m+p+2i)} \\ &= \Sigma_{-(2i-1)}^{2i-1} (-1)^m (2i+\pi) q^{m(m+\pi)} + \Sigma_1^{\infty} (-1)^m (4i+2p) p q^{m(m+p+2i)}. \end{aligned}$$

The second refers to page 78; there we have the following equation—

$$\Sigma \Sigma (-1)^{m+p} p q^{m(m+p)} = \Sigma \psi(m) q^{2m}.$$

It would be better to write this in the following way—

$$\Sigma \Sigma (-1)^{m+p} p q^{m(m+p)} = \Sigma \psi(r) q^{2r},$$

since $m(m+p)$ and $2r$ are intended to be equivalent.

Section 3.—Jacobi's second paper is entitled "Ueber die partielle Differentialgleichung welcher die Zähler und Nenner der elliptischen Function Genüge leisten." Jacobi at the commencement of his paper gives the following formula without demonstration:—

$$\theta_3(x) = \sqrt{\frac{2K}{\pi}} \Delta e^{\int_0^x E(u) du - \frac{E^2 x^2}{K}}.$$

To prove this, we remember the well-known expression

$$\theta(x) = \sqrt{\frac{2Kk'}{\pi}} e^{\int_0^x \frac{F'E\phi - E'F\phi}{F'\Delta\phi} d\phi};$$

$\theta_3(x)$ is derived from $\theta(x)$ by changing q into $-q$.

Now if we change q into $-q$,

$$\sqrt{\frac{2Kk'}{\pi}} \text{ becomes } \sqrt{\frac{2K}{\pi}}, F' = K \text{ becomes } Kk',$$

$$E' \text{ becomes } \frac{E'}{k'}, \Delta \text{ becomes } \frac{1}{\Delta},$$

$$E\phi = \int_0^\phi d\phi \sqrt{1-k^2 \sin^2 \phi} \text{ becomes } k' \int_0^\phi \frac{d\phi}{\Delta^3},$$

$$\text{and } \int_0^\phi \frac{d\phi}{\Delta^3} = \frac{1}{k'^2} E\phi - \frac{k^2}{k'^2} \frac{\sin \phi \cos \phi}{\Delta} \dagger,$$

and therefore $E\phi$ becomes

$$\frac{1}{k'} E\phi - \frac{k^2}{k'} \frac{\sin \phi \cos \phi}{\Delta}.$$

$$F\phi \text{ becomes } k'F\phi, \text{ and } \frac{d\phi}{\Delta} \text{ becomes } k' \frac{d\phi}{\Delta}.$$

Substituting all these in the expression for $\theta(x)$, we have

$$\begin{aligned} \theta_3(x) &= \sqrt{\frac{2K}{\pi}} e^{\int_0^\phi \left\{ \frac{1}{k'} E\phi - \frac{k^2}{k'} \frac{\sin \phi \cos \phi}{\Delta} - \frac{E'}{Kk'} F\phi \right\} \frac{k'd\phi}{\Delta}} \\ &= \sqrt{\frac{2K}{\pi}} e^{\int_0^\phi \frac{E\phi d\phi}{\Delta} - \frac{1}{2} \frac{F'}{K} F(\phi)^2 + \log_e \Delta} \\ &= \sqrt{\frac{2K}{\pi}} \Delta e^{\int_0^\phi \frac{E\phi d\phi}{\Delta} - \frac{1}{2} \frac{E'}{K} E\phi^2}, \end{aligned}$$

which is, in fact, Jacobi's expression for $\theta_3(x)$. In the memoir now under consideration, Jacobi arrives by partial differentiation at the following theorem:

Let

$$Y = \int_0^t t^{\beta-1} (1-t)^{\gamma-\beta-1} (1-rt)^{-\alpha} dt,$$

$$y = \int_0^1 t^{\beta-1} (1-t)^{\gamma-\beta-1} (1-rt)^{-\alpha} dt,$$

$$\lambda = \int r^{-\gamma} (1-r)^{\gamma-\alpha-\beta-1} y^2 dr, \quad v = \frac{Y}{y},$$

* Fundamenta Nova, p. 111.

† Hymers's Integral Calculus, p. 220.

$$V = \frac{1}{2} r^\gamma (1-r)^{\alpha+\beta-\gamma+1} \left(Y \frac{dY}{dr} - Y \frac{dY}{dt} \right) \\ = \frac{1}{2} \alpha^\beta (1-t)^{\gamma-\beta} \int r^{\gamma-1} (1-r)^{\alpha+\beta-\gamma} (1-rt)^{-\alpha-1} Y dr :$$

then V , considered as a function of v and λ , satisfies the partial differential equation

$$\frac{dV}{d\lambda} - 2V \frac{dV}{dv} + r^{\gamma-1} (1-r)^{\alpha+\beta-\gamma} t^{2\beta-1} (1-t)^{2\gamma-2\beta-1} (1-rt)^{-2\alpha+1} \frac{d^2V}{dv^2} = 0.$$

Let $\gamma=1$, $\alpha=\beta=\frac{1}{2}$, and the differential equation becomes

$$\frac{dV}{d\lambda} - \frac{d \cdot V^2}{dv} - \frac{d^2V}{dv^2} = 0,$$

and Y becomes

$$\int_0^t \frac{dt}{\sqrt{r(1-t)(1-rt)}} = 2 \int_0^\phi \frac{d\phi}{\sqrt{1-r \sin^2 \phi}},$$

where $t = \sin^2 \phi$.

From this Jacobi shows that

$$\theta_{3^2} = \sqrt{\frac{2K}{\pi}} \Delta e \int_0^u \text{Eud}u - 1 \frac{E' u^2}{K}$$

satisfies the partial differential equation, originally seen to be true from the nature of the series

$$-4q \frac{d\theta_3(x)}{dq} = \frac{d^2\theta_3(x)}{dx^2}.$$

Section 4.—Jacobi's third paper is a very remarkable one, and there is a French translation in Liouville's Journal. It is entitled "Ueber die Differentialgleichung welcher die Reihen $1 \pm 2q + 2q^4 \pm \dots 2^i \sqrt{q} + 2^i \sqrt{q^9} + \dots$ Genüge leisten."

The main object of the paper is to show that

$$y = \sqrt{\frac{2K}{\pi}}, \quad y = \sqrt{\frac{2Kk}{\pi}}, \quad y = \sqrt{\frac{2Kk'}{\pi}},$$

each satisfy the following differential equation,

$$\{y^2 d^2 y - 15y dy d^2 y + 30dy\} + 32\{y d^2 y - 3dy^2\}^2 = y^{10} \{y d^2 y - 3dy^2\}^2 (d \log_e q)^2.$$

By differentiating the equation

$$K = \int_0^\pi \sqrt{1 - k^2 \sin^2 \theta}$$

with respect to k^2 it is proved without much difficulty that if $y = \sqrt{\frac{2K}{\pi}}$,

$$\frac{d \cdot k^2 \frac{d}{dk^2} \frac{d \cdot y^2}{dk^2}}{dk^2} = \frac{y^2}{4} \dots \dots \dots (1)$$

and from this that

$$\frac{d \cdot \log_e \frac{k^2}{k'^2}}{d \log_e q} = y^4 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Combining these equations together, we have

$$\frac{4}{y^6} \left(\frac{d}{d \log_e q} \right)^2 \frac{1}{y^2} = -k^2 k'^2,$$

from whence we obtain

$$d \log_e \left\{ \frac{1}{y^6} \cdot \frac{d^2}{(d \log_e q)^2} \cdot \frac{1}{y^2} \right\} = \sqrt{\left\{ \frac{16}{y^6} \cdot \frac{d^2}{(d \log_e q)^2} \cdot \frac{1}{y^2} + 1 \right\}} y^4 d \log_e q^*,$$

which immediately leads to the required differential equation. A similar investigation applies to $y = \sqrt{\frac{2Kk}{\pi}}$, $y = \sqrt{\frac{2Kk'}{\pi}}$.

We may find a more general solution of Jacobi's differential equation thus

It is easily proved that if k and k' are interchanged, equation (1) is unaltered, and therefore K' is a particular solution of it. Therefore

$$Q = aK + b\sqrt{-1K'}, \quad Q' = a'K + b'\sqrt{-1K'}$$

are also solutions of equation (1), and consequently

$$\frac{d}{d \cdot k^2} k^2 k'^2 \frac{d}{dk^2} \cdot \left\{ \frac{2Q}{\pi} \right\} = \frac{1}{2} \left\{ \frac{2Q}{\pi} \right\}.$$

Moreover, it is proved in the 'Fundamenta Nova,' p. 74, that

$$d \cdot \frac{-\pi Q'}{Q} = \frac{(aa' + bb') d \log_e \frac{k^2}{k'^2}}{\left(\frac{2Q}{\pi} \right)^2}.$$

These equations exactly correspond with (1) and (2), and therefore

$$y = \sqrt{\frac{2Q}{\pi \sqrt{aa' + bb'}}}, \quad \log_e q = -\frac{\pi Q'}{Q}$$

satisfy Jacobi's differential equation.

Section 5.—In close connexion with this paper is another left by Jacobi among his manuscripts, "Darstellung der elliptischen Functionen durch Potenzreihen," published in the fifty-fourth volume of Crelle's Journal. Its object is to expand the four functions $\theta(x)$, $\theta_1(x)$, $\theta_2(x)$, $\theta_3(x)$ in terms of (x) . I shall give the outlines of the investigation for $\theta_3(x)$.

* Because $\frac{d \log_e k^2 k'^2}{d \log_e q} = \left\{ \frac{1}{k^2} - \frac{1}{k'^2} \right\} \frac{dk^2}{d \log_e q} = \sqrt{1 - 4k^2 k'^2} \frac{d \log_e \frac{k^2}{k'^2}}{d \log_e q}$. I have followed a route somewhat differing from Jacobi's, and easier if we only wish for the differential equation for $\sqrt{\frac{2K}{\pi}}$. I should advise the reader to follow the method for $y = \sqrt{\frac{2K}{\pi}}$ indicated here, and then to read Jacobi entire.

It is easily seen that if

$$h = \log_e \sqrt{\gamma}, \quad \Lambda = \frac{2K}{\pi},$$

$$\frac{d^{2m} \theta_3(x)}{d\Lambda^{2m}} = (-1)^m \frac{d^m}{dh^m} \sqrt{\frac{2K}{\pi}} = (-1)^m \frac{d^m \sqrt{\Lambda}}{dh^m};$$

$$\therefore \theta_3(x) = \sqrt{\Lambda} - \frac{d\sqrt{\Lambda}}{dh} \cdot \frac{1}{1.2} + \frac{d^2\sqrt{\Lambda}}{dh^2} \cdot \frac{1}{1.2.3.4} + \dots \quad (1)$$

and therefore, putting $B = \frac{2k^2}{\pi} \int_0^\pi \frac{\cos^2 \phi}{\sqrt{1-k^2 \sin^2 \phi}} d\phi$,

$$a = 4(1-2k^2), \quad b = 2k^2 k'^2,$$

we obtain, by a process similar to that used in obtaining equations (1) and (2) of last article,

$$\frac{d\Lambda}{dh} = 2\Lambda^2 B, \quad \frac{dB}{dh} = b\Lambda^3, \quad \frac{da}{dh} = -16b\Lambda^2, \quad \frac{db}{dh} = ab\Lambda^2 \quad \dots \quad (2)$$

If H is a function of Λ , B , a , b , we obtain from these equations the following:—

$$\frac{dH}{dh} = 2\Lambda^2 B \frac{dH}{d\Lambda} + b\Lambda^3 \frac{dH}{dB} + ab\Lambda^2 \frac{dH}{da} - 16ba^2 \frac{dH}{db} \quad \dots \quad (3)$$

Differentiating $\sqrt{\Lambda}$ a certain number of times in accordance with (3), we are led to suspect that

$$\left. \begin{aligned} \frac{d^m \sqrt{\Lambda}}{dh^m} &= n_1^{(m)} \Lambda^{\frac{2m+1}{2}} B^m + n_2^{(m)} r_2 \Lambda^{\frac{2m+1}{2}+2} B^{m-2} \\ &+ n_3^{(m)} r_3 \Lambda^{\frac{2m+1}{2}+3} B^{m-3} + \dots + n_i^{(m)} r_i \Lambda^{\frac{2m+1}{2}+i} B^{m-i} + \dots \\ &+ n_m^{(m)} r_m \Lambda^{\frac{2m+1}{2}+m}, \end{aligned} \right\} \quad (4)$$

where $n_1^{(m)}$, $n_2^{(m)}$, &c. are certain integers, r_2 , r_3 , &c. certain functions of a and b independent of (m) ; so that the coefficient of $\Lambda^{\frac{2m+1}{2}+i+p} B^{m+p-i}$ in the expansion of $\frac{d^{m+p} \sqrt{\Lambda}}{dh^{m+p}}$ is $n^{(m+p)} r_i$. It will be observed that $r_1 = 0$.

Furthermore, we are led by induction to suspect that the numbers $n^{(m)}$ are such that

$$\theta_3(x) = \sqrt{\Lambda} e^{-\frac{1}{2}ABx^2} \left\{ 1 + r_2 \frac{\Lambda^4 x^4}{1.2.3.4} - r_3 \frac{\Lambda^6 x^6}{1.2.3.4.5.6} + \dots \right\} \quad (5)$$

These assumptions may be thus verified:—

Equating coefficients in the two expressions for θ_3 &c. in (1) and (5), we have

$$\frac{d^m \sqrt{A}}{dh^m} = A^{\frac{2m+1}{2}} \left\{ m_0 B^m + m_2 r_2 B^{m-2} A^2 + \dots + m_{m-3} B^{m-3} A^3 + \dots + m_m r_m A^m \right\}, \quad (6)$$

where the coefficient

$$m_i = (2i+1)(2i+3)\dots(2m-1) \cdot \frac{m(m-1)\dots(m-i+1)}{1 \cdot 2 \cdot 3 \dots i}; \quad (7)$$

we find from (6), in consequence of (3), that

$$\begin{aligned} & \{ (2m+2i+1)m_i - (m+1)_i \} r_i + (m-i+2)m_{i-2} b r_{i-2} \\ & + m_{i-1} a b \frac{dr_{i-1}}{db} - 16 m_{i-1} b \frac{dr_{i-1}}{da} = 0, \end{aligned}$$

which being transformed by means of (7), gives

$$r_i - (i-1)(2i-3)b r_{i-2} = b \left\{ a \frac{dr_{i-1}}{db} - 16 \frac{dr_{i-1}}{da} \right\},$$

which is independent of (m) , as it should be, according to the assumption.

Moreover the value of $\frac{d^{m+1} \sqrt{A}}{dh^{m+1}}$ found by equating coefficients in (1) and (5) is

$$\frac{d^{m+1} \sqrt{A}}{dh^{m+1}} = A^{\frac{2m+3}{2}} \{ (m+1)_0 B^{m+1} + (m+1)_2 r_2 B^{m-1} A^2 + \dots \};$$

and this can also be found by differentiating (6) with regard to h . The induction is completely proved. I think the reader will find no difficulty after these remarks in reading this paper,—one of the most beautiful productions of its illustrious author, the paper reviewed in last section having been previously studied.

Section 6.—In the thirty-seventh volume of Crelle's Journal there is a memoir of Jacobi of a very different nature to those we have been reviewing. Its title is "Ueber unendliche Reihen, deren exponenten zugleich in zwei verschiedenen quadratischen Formen enthalten sind." Many parts of this memoir relate to the theory of numbers, and contain no allusion whatever to the subject of this Report; nevertheless, as these investigations were suggested by a formula in the 'Fundamenta Nova,' it will be right to give some account of it here.

From the well-known formula in the 'Fundamenta Nova,'

$$\begin{aligned} & (1-q^2)(1-q^4)(1-q^6)\dots(1-qz)(1-q^2z)(1-q^4z)\dots \\ & (1-qz^{-1})(1-q^3z^{-1})(1-q^5z^{-1})\dots = \\ & 1 - q(z+z^{-1}) + q^4(z^3+z^{-3}) - q^9(z^5+z^{-5}) + \dots, \end{aligned}$$

we deduce, by putting q^n for q and $\pm q^{\pm n}$ for z , the following expressions:—

$$\Pi \{ (1-q^{2mi+m-n})(1-q^{2mi+m+n})(1-q^{2mi+2m}) \} = \Sigma (-1)^i q^{m^2+ni} \dots \quad (I.)$$

$$\Pi \{ (1+q^{2mi+m-n})(1+q^{2mi+m+n})(1-q^{2mi+2m}) \} = \Sigma q^{m^2+ni} \dots \quad (II.)$$

It is easy to see that these equations will lead to a multitude of others of
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the form

$$\Pi(1-q^{a_1 i + \beta})(1-q^{a_2 i + \beta})(1-q^{a_3 i + \beta}) \dots = \Sigma \Sigma (-1)^{i+k} q^{a i^2 + b k^2 + c i + c k},$$

where i in the products has the values 0, 2, 3, &c., and in the summations i and k have the values 0, ± 1 , ± 2 , ± 3 , &c.

Jacobi has given a Table of these equations. I select three of them for demonstration, which will give an idea of the whole sufficient for our present purpose.

$$(1) \quad \Pi\{(1-q)^{6i+2}(1-q^{3i+3})^2(1-q^{6i+4})\} = \Sigma(-1)^{i+k} q^{3i^2 + 3k^2 + i},$$

$$(2) \quad \Pi\{(1-q^{3i+1})(1-q^{3i+2})(1-q^{6i+3})^3(1-q^{6i+6})^2\} \\ = \Sigma(-1)^{i+k} q^{\frac{1}{2}(3i^2 + 6k^2 + i)},$$

$$(3) \quad \Pi\{(1-q^{4i+2})^3(1-q^{4i+4})^2\} = \Sigma(-1)^{i+k} q^{3i^2 + 2k^2 + i}.$$

By the formula (I.),

$$\Sigma(-1)^{i+k} q^{3i^2 + 3k^2 + i} =$$

$$\Pi\{(1-q)^{6i+3}(1-q^{6i+3})(1-q^{6i+6})\Pi(1-q^{6i+2})(1-q^{6i+4})(1-q^{6i+6})\},$$

consequently formula (1.) reduces itself to

$$\Pi(1-q^{3i+3})^2 = \Pi(1-q^{6i+3})^2(1-q^{6i+6})^2,$$

or

$$\Pi(1-q^{3i+3}) = \Pi(1-q^{6i+3})(1-q^{6i+6}),$$

which is at once seen to be true.

To prove the second formula, we observe that

$$\Sigma(-1)^{i+k} q^{\frac{1}{2}(3i^2 + 6k^2 + i)}$$

by formula (I.) is equivalent to

$$\Pi(1-q^{3i+1})(1-q^{3i+2})(1-q^{3i+3})\Pi(1-q^{6i+3})(1-q^{6i+3})(1-q^{6i+6});$$

and the equation reduces itself to

$$\Pi(1-q^{6i+3})(1-q^{6i+6}) = \Pi(1-q^{3i+3}),$$

the same as before.

We also have

$$\Sigma(-1)^{i+k} q^{\frac{1}{2}(3i^2 + 6k^2 + i)} = \Pi(1-q^{2+i})(1-q^{6i+3})(1-q^{3i+3}),$$

a formula not noticed by Jacobi.

To prove formula (3), we have

$$\Sigma(-1)^{i+k} q^{3i^2 + 2k^2 + i}$$

$$= \Pi(1-q^{6i+2})(1-q^{6i+4})(1-q^{6i+6})\Pi(1-q^{4i+2})(1-q^{4i+2})(1-q^{4i+4});$$

and the equation reduces itself to

$$\Pi(1-q^{6i+2})(1-q^{6i+4})(1-q^{6i+6}) = \Pi(1-q^{4i+2})(1-q^{4i+4}),$$

each member of which is immediately seen to be equivalent to $\Pi(1-q^{2i+2})$.

In this manner the following expressions for the modulus are deduced which will be found demonstrated on pages 76 and 77.

From

$$\begin{aligned}\sqrt{k'} &= \frac{(1-q)(1-q^3)(1-q^5) \dots}{(1+q)(1+q^3)(1+q^5) \dots} & \sqrt[4]{k} &= \sqrt[8]{q} \frac{(1+q^2)(1+q^4)(1+q^6) \dots}{(1+q)(1+q^3)(1+q^5) \dots}, \\ \sqrt[4]{k'} &= \frac{\Sigma(-1)^i q^{\frac{1}{2}(3i^2+i)}}{\Sigma(-1)^{\frac{i(i+1)}{2}} q^{\frac{1}{2}(3i^2+i)}} = \frac{\Sigma(-1)^i q^{2i^2+i}}{\Sigma q^{2i^2+i}} \\ &= \frac{\Sigma(-1)^i q^{i^2}}{\Sigma(-1)^i q^{2i^2}} = \frac{\Sigma(-1)^i q^{2i^2}}{\Sigma q^{4i^2}}, \\ \sqrt[4]{k} &= \frac{\sqrt{2} \sqrt[8]{q} \Sigma(-1)^i q^{\frac{1}{2}(6i^2+2i)}}{\Sigma(-1)^{\frac{i(i+1)}{2}} q^{\frac{1}{2}(3i^2+i)}} = \frac{\sqrt{2} \sqrt[8]{q} \Sigma q^{4i^2+2i}}{\Sigma q^{3i^2+i}} \\ &= \frac{\sqrt{2} \sqrt[8]{q} \Sigma(-1)^i q^{2i^2+i}}{\Sigma(-1)^i q^{2i^2}} = \frac{\sqrt{2} \sqrt[8]{q} \Sigma q^{2i^2+2}}{\Sigma q^{2i^2}}.\end{aligned}$$

Section 7.—Two papers by Heine next come under our notice. The first of these, “Untersuchungen über die Reihe

$$1 + \frac{(1-q^\alpha)(1-q^\beta)}{(1-q)(1-q^\gamma)} x + \frac{(1-q^\alpha)(1-q^{\alpha+1})(1-q^\beta)(1-q^{\beta+1})}{(1-q)(1-q^\alpha)(1-q^\gamma)(1-q^{\gamma+1})} x^2 + \dots,”$$

is in the thirty-fourth volume of Crelle's Journal.

This series is denoted by Heine by the symbols $\phi(\alpha, \beta, \gamma)$ or $\phi(\alpha, \beta, \gamma, q, x)$, as may be most convenient. I shall consider those parts of the paper which relate to elliptic functions. Heine commences by showing that the elliptic functions

$$\begin{aligned}\frac{2k'K}{\pi} \frac{\cos \operatorname{am} \frac{2Kx}{\pi}}{\cos \operatorname{coam} \frac{2Kx}{\pi}}, & \quad \frac{2K}{\pi} \frac{\sin \operatorname{am} \frac{2Kx}{\pi}}{\sin \operatorname{coam} \frac{2Kx}{\pi}}, \\ \frac{2k^2K}{\pi} \frac{\sin \operatorname{am} \frac{2Kx}{\pi}}{\sin \operatorname{coam} \frac{2Kx}{\pi}}, & \quad \frac{2K}{\pi} \frac{\sin \operatorname{coam} \frac{2Kx}{\pi}}{\sin \operatorname{am} \frac{2Kx}{\pi}}, \\ \frac{2K}{\pi \sin \operatorname{coam} \frac{2Kx}{\pi}}, & \quad \frac{2kK}{\pi} \frac{\sin \operatorname{coam} \frac{2Kx}{\pi}}{\sin \operatorname{am} \frac{2Kx}{\pi}}\end{aligned}$$

can all be expressed by means of this series.

Thus we find $\frac{2kK}{\pi} \sin \operatorname{coam} \frac{2Kx}{\pi}$ equivalent to

$$\frac{2\sqrt{q}}{1-q} \{ e^{ix} \phi(1, \tfrac{1}{2}, \tfrac{3}{2}, q^2, -q e^{2ix}) + e^{-ix} \phi(1, \tfrac{1}{2}, \tfrac{3}{2}, q^2, q e^{-2ix}) \},$$

as is immediately seen by expanding the functions.

Following the methods employed by Gauss for the hypergeometrical series, Heine deduces a large number of equations, easy of proof, of which I write down the following:—

$$\left. \begin{aligned}\phi(\alpha, \beta, \gamma, q, x) - \phi(\alpha, \beta, \gamma, q, qx) \\ = \frac{(1-q^\alpha)(1-q^\beta)}{1-q^\gamma} x \phi(\alpha+1, \beta+1, \gamma+1, q, x)\end{aligned} \right\} \dots \quad (1)$$

$$\left. \begin{aligned}(1-q^\gamma)(1-q^{\alpha+\beta-\gamma}x) \phi(\alpha+1, \beta, \gamma) + q^{\alpha+\beta-\gamma} x (1-q^{\gamma-\beta}) \phi(\alpha+1, \beta, \gamma+1) \\ - (1-q^\gamma) \phi(\alpha, \beta, \gamma) = 0\end{aligned} \right\} \quad (2)$$

$$\begin{aligned} \phi(\alpha, \beta, \gamma-1) - \phi(\alpha, \beta, \gamma) \\ = q^{\gamma-1} x \frac{(1-q^\alpha)(1-q^\beta)}{(1-q^{\gamma-1})(1-q^\gamma)} \phi(\alpha+1, \beta+1, \gamma+1) \quad . \quad . \quad . \quad (3) \end{aligned}$$

$$\begin{aligned} \phi(\alpha, \beta+1, \gamma+1) - \phi(\alpha, \beta, \gamma) \\ = q^{\beta} x \frac{1-q^\alpha}{1-q^\gamma} \frac{1-q^{\gamma-\beta}}{1-q^{\gamma+1}} \phi(\alpha+1, \beta+1, \gamma+2) \quad . \quad . \quad . \quad (4) \end{aligned}$$

$$\phi(\alpha, \beta+1, \gamma) - \phi(\alpha, \beta, \gamma) = q^{\beta} x \frac{1-q^\alpha}{1-q^\gamma} \phi(\alpha+1, \beta+1, \gamma+1) \quad . \quad . \quad (5)$$

$$\phi(\alpha+1, \beta, \gamma) - \phi(\alpha, \beta, \gamma) = q^{\alpha} x \frac{1-q^\beta}{1-q^\gamma} \phi(\alpha+1, \beta+1, \gamma+1) \quad . \quad . \quad (6)$$

$$\begin{aligned} \phi(\alpha+1, \beta, \gamma+1) \\ = q^{\alpha} x \frac{(1-q^\beta)(1-q^{\gamma-\alpha})}{(1-q^\gamma)(1-q^{\gamma+1})} \phi(\alpha+1, \beta+1, \gamma+2) \quad . \quad . \quad . \quad (7) \end{aligned}$$

$$\begin{aligned} \phi(\alpha-1, \beta+1, \gamma) - \phi(\alpha, \beta, \gamma) \\ = -q^{\alpha-1} x \frac{1-q^{\beta-\alpha+1}}{1-q^\gamma} \phi(\alpha, \beta+1, \gamma+1) \quad . \quad . \quad . \quad (8) \end{aligned}$$

$$\begin{aligned} \phi(\alpha+1, \beta-1, \gamma) - \phi(\alpha, \beta, \gamma) \\ = q^{\alpha} x \frac{1-q^{\beta-\alpha-1}}{1-q^\gamma} \phi(\alpha+1, \beta, \gamma+1) \quad . \quad . \quad . \quad (9) \end{aligned}$$

These formulæ are applied by Heine to the expression of the fundamental series in continued fractions. Thus from (4) we immediately obtain

$$\frac{\phi(\alpha, \beta+1, \gamma+1)}{\phi(\alpha, \beta, \gamma)} = \frac{1}{1 - q^{\beta} x \frac{(1-q^{\alpha})(1-q^{\gamma-\beta})}{(1-q^{\gamma})(1-q^{\gamma+1})} \cdot \frac{\phi(\alpha+1, \beta+1, \gamma+2)}{\phi(\alpha, \beta+1, \gamma+1)}}$$

Since

$$\frac{\phi(\alpha+1, \beta+1, \gamma+2)}{\phi(\alpha, \beta+1, \gamma+1)} = \frac{\phi(\beta+1, \alpha+1, \gamma+2)}{\phi(\beta+1, \alpha, \gamma+1)},$$

by the very nature of the series represented by the functions, we can repeat this process and expand $\frac{\phi(\alpha, \beta+1)(\gamma+1)}{\phi(\alpha, \beta, \gamma)}$ in a continued fraction. The result is

$$\frac{\phi(\alpha, \beta+1, \gamma+1)}{\phi(\alpha, \beta, \gamma)} = \frac{1}{1 - \frac{\alpha_1 x}{1 - \frac{\alpha_2 x}{1 - \frac{\alpha_3 x}{1 - \frac{\alpha_4 x}{1 - \dots}}}}}$$

where

$$\begin{aligned} \alpha_1 &= q^{\beta} \frac{(1-q^{\alpha})(1-q^{\gamma-\beta})}{(1-q^{\gamma})(1-q^{\gamma+1})}, & \alpha_2 &= q^{\alpha} \frac{(1-q^{\beta+1})(1-q^{\gamma-\alpha+1})}{(1-q^{\gamma+1})(1-q^{\gamma+2})}, \\ \alpha_3 &= q^{\beta+1} \frac{(1-q^{\alpha+1})(1-q^{\gamma-\beta+1})}{(1-q^{\gamma+2})(1-q^{\gamma+3})}, & \alpha_4 &= q^{\alpha+1} \frac{(1-q^{\beta+2})(1-q^{\gamma-\alpha+2})}{(1-q^{\gamma+3})(1-q^{\gamma+4})}. \end{aligned}$$

When $\beta=0$, $\phi(\alpha, \beta, \gamma)$ becomes unity, and we obtain a continued fraction for $\phi(1, \alpha, \gamma+1)$, which is immediately applicable to elliptic functions.

From the nature of the series we have at once

$$\phi(\alpha+1, \beta+1, \beta+1) = \phi(\alpha+1, \beta, \beta).$$

Consequently putting $\beta = \gamma = 1$ in (1) and (6), we immediately obtain the following equation:—

$$\phi(\alpha, 1, 1, q, x) = \frac{1 - q^{\alpha}x}{1 - x} \phi(\alpha, 1, 1, q, qx);$$

$$\therefore \phi(\alpha, 1, 1, q, x) = \frac{(1 - q^{\alpha}x) \dots (1 - q^{\alpha+n-1}x)}{(1 - x) \dots (1 - q^{n-1}x)} \phi(\alpha, 1, 1, q, q^n x);$$

and since q is supposed less than unity, the series $\phi(\alpha, 1, 1, q, q^n x)$ always approaches unity as (n) indefinitely increases, and consequently

$$\phi(\alpha, 1, 1, q, x) = \frac{(1 - q^{\alpha}x)(1 - q^{\alpha+1}x)(1 - q^{\alpha+2}x) \dots}{(1 - x)(1 - qx)(1 - q^2x) \dots} \quad \dots \quad (10)$$

Again, putting $x = q^{\gamma - \alpha - \beta}$ in series (2), we have

$$\phi(\alpha, \beta, \gamma, q, q^{\gamma - \alpha - \beta}) = \frac{1 - q^{\gamma - \beta}}{1 - q^{\gamma}} \phi(\alpha + 1, \beta, \gamma + 1, q, q^{\gamma - \alpha - \beta});$$

and repeating this process,

$$\phi(\alpha, \beta, \gamma, q, q^{\gamma - \alpha - \beta}) = \frac{(1 - q^{\gamma - \beta}) \dots (1 - q^{\gamma - \beta + n - 1})}{(1 - q^{\gamma}) \dots (1 - q^{\gamma + n - 1})} \phi(\alpha + n, \beta, \gamma + n, q, q^{\gamma - \alpha - \beta}).$$

Now we have generally

$$\begin{aligned} &\phi(\alpha + n, \beta, \gamma + n, q, x) \\ &= 1 + \frac{(1 - q^{\alpha+n})(1 - q^{\beta})}{(1 - q)(1 - q^{\gamma+n})} x + \frac{(1 - q^{\alpha+n})(1 - q^{\alpha+n-1})(1 - q^{\beta})(1 - q^{\beta+1})}{(1 - q)(1 - q^2)(1 - q^{\gamma+n})(1 - q^{\gamma+n-1})} x^2 + \dots \end{aligned}$$

As (n) increases without limit, this series approaches

$$1 + \frac{1 - q^{\beta}}{1 - q} x + \frac{(1 - q^{\beta})(1 - q^{\beta+1})}{(1 - q)(1 - q^2)} x^2 + \dots = \phi(\beta, 1, 1, q, x).$$

Hence when (n) is infinite, we have by (10)

$$\phi(\alpha + n, \beta, \gamma + n, q, q^{\gamma - \alpha - \beta}) = \frac{(1 - q^{\gamma - \alpha})(1 - q^{\gamma - \alpha + 1}) \dots}{(1 - q^{\gamma - \alpha - \beta})(1 - q^{\gamma - \alpha - \beta + 1}) \dots},$$

and therefore

$$\begin{aligned} &\phi(\alpha, \beta, \gamma, q, q^{\gamma - \alpha - \beta}) \\ &= \frac{(1 - q^{\gamma - \alpha})(1 - q^{\gamma - \alpha + 1}) \dots}{(1 - q^{\gamma})(1 - q^{\gamma + 1}) \dots} \frac{(1 - q^{\gamma - \beta})(1 - q^{\gamma - \beta + 1}) \dots}{(1 - q^{\gamma - \alpha - \beta})(1 - q^{\gamma - \alpha - \beta + 1}) \dots} \quad \dots \quad (11) \end{aligned}$$

From these formulæ it will readily be perceived that the leading properties of functions θ can be deduced. For the details I refer to Heine's second paper, "Abriss einer Theorie der elliptischen Functionen," which will be found in the thirty-ninth volume of Crelle's Journal, and which, after the remarks here made, will offer no difficulty.

There are some consequences of formula (11) just proved which I shall insert in this place.

If we put

$$\omega(q, a) = \frac{(1 - q)(1 - q^2)(1 - q^3) \dots}{(1 - q^{a+1})(1 - q^{a+2})(1 - q^{a+3}) \dots}$$

we shall obtain from (11)

$$\phi(\alpha, \beta, \gamma, q, q^{\gamma-\alpha-\beta}) = \frac{\omega(q, \gamma-1)\omega(q, \gamma-\alpha-\beta-1)}{\omega(q, \gamma-\alpha-1)\omega(q, \gamma-\beta-1)}.$$

From this Heine deduces easily

$$\phi\left(\frac{1}{2} + \frac{x^2}{\log_e q}, \frac{1}{2} - \frac{x^2}{\log_e q}, 2, q^2, q^2\right) = \frac{\omega(q^2, 1)\omega(q^2, 1)}{\omega\left(q^2, \frac{1}{2} - \frac{x^2}{\log_e q}\right)\omega\left(q^2, \frac{1}{2} + \frac{x^2}{\log_e q}\right)},$$

whence we have

$$\theta(x) = \theta_1(0)^* \cdot \frac{1-2q \cos 2x + q^2}{2\sqrt{q}} \cdot \frac{1}{1-q^2} \left\{ 1 + \frac{(1-2q \cos 2x + q^2)}{(1-q^2)(1-q^4)} q^2 + \frac{(1-2q \cos 2x + q^2)(1-2q \cos 2x + q^2)}{(1-q^2)(1-q^4)(1-q^4)} q^4 + \dots \right\},$$

and a similar formula for θ, x .

Heine also gives some formulae for the multiplication of elliptic functions, of which I shall give one here.

From the equation

$$\omega(q^n, \alpha) \omega\left(q^n, \alpha - \frac{1}{n}\right) \omega\left(q^n, \alpha - \frac{2}{n}\right) \dots \omega\left(q^n, \alpha - \frac{n-1}{n}\right) = c \omega(q, n\alpha),$$

where

$$c = \frac{\{(1-q^n)(1-q^{2n})(1-q^{3n}) \dots\}^n}{(1-q)(1-q^2)(1-q^3) \dots},$$

we have, where (n) is odd,

$$\prod_{m=0}^{m=n-1} \Theta\left\{q^n, \frac{2K_n}{\pi}(b - mi \log q)\right\} = \frac{(-1)^{\frac{1}{2}(n-1)}}{q^{\frac{1}{2}(n-1)^2}} h \Theta\left(q, \frac{2Kh}{\pi}\right),$$

and when (n) is even,

$$\prod_{m=0}^{m=n-1} \Theta\left\{q^n, \frac{2K_n}{\pi}(b - mi \log_e q)\right\} = - \frac{i(-1)^{\frac{1}{2}n} e^{i\pi}}{\sqrt[n]{q} q^{\frac{1}{2}(n-1)^2}} h \Pi\left(q, \frac{2Kh}{\pi}\right),$$

where $\Theta\left(q^n, \frac{2K_n}{\pi}\right)$ bears the same relation to q^n that $\Theta\left(\frac{2Kh}{\pi}\right)$ does to q , and

$$h = \frac{\{(1-q^{2n})(1-q^{4n}) \dots\}}{(1-q^2)(1-q^4) \dots}.$$

Section 8.—The comparative simplicity of the functions θ naturally suggested to mathematicians the utility of adopting these series as ground-forms in the theory of elliptic transcendents. These functions have therefore been in these last times the subject of many investigations. Among the memoirs relating to these series, three may be particularly mentioned as having remarkably contributed to the advancement of our knowledge of their properties. These three papers are Jacobi's memoir "Sur la Rotation d'un Corps," in the thirty-ninth volume of Crelle's Journal, a paper by Krusemark, "Zur Theorie der elliptischen Functionen," in the forty-sixth volume, and a paper by Richelot, "Ueber eine Merkwürdige Formel in der Theorie der elliptischen

* For the value of $\theta_1(0)$ see a little further on.

Transcendenten," in the fiftieth volume of the same Journal. These methods have been admirably harmonized and developed by Schellbach in his 'Lehre von den elliptischen Integralen und den Thetafunctionen,' Berlin, 1864. I proceed to lay a summary of the results thus obtained before the reader, accompanied by such remarks as may obviate difficulties. I commence by writing in full the notation to be employed.

$$\theta(x) = 1 - 2q \cos 2x + 2q^4 \cos 4x - 2q^9 \cos 6x + \dots,$$

$$\theta_1(x) = 2q^{\frac{1}{4}} \sin x - 2q^{\frac{9}{4}} \sin 3x + 2q^{\frac{25}{4}} \sin 5x - \dots,$$

$$\theta_2(x) = 2q^{\frac{1}{4}} \cos x + 2q^{\frac{9}{4}} \cos 3x + 2q^{\frac{25}{4}} \cos 5x + \dots,$$

$$\theta_3(x) = 1 + 2q \cos 2x + 2q^4 \cos 4x + 2q^9 \cos 6x + \dots$$

If $q = e^{-\nu}$, we shall sometimes use the following abbreviations for the four series, $\theta(x, \nu)$, $\theta_1(x, \nu)$, $\theta_2(x, \nu)$, $\theta_3(x, \nu)$. Let also

$$f(x) = \frac{\theta_1 x}{\theta x}, \quad gx = \frac{\theta_2 x}{\theta x}, \quad hx = \frac{\theta_3 x}{\theta x}.$$

Then

$$\sin \text{am } \frac{2Kx}{\pi} = \frac{1}{\sqrt{k}} f(x), \quad \cos \text{am } \frac{2Kx}{\pi} = \frac{\sqrt{k'}}{\sqrt{k}} gx,$$

$$\Delta \text{ am } \frac{2Kx}{\pi} = \sqrt{k'} hx.$$

The periods of these functions are given by Schellbach (section 22, p. 34).

By direct multiplication we find that

$$\theta_3 x \theta_3 y = \theta_3(x+y, 2\nu) \theta_3(x-y, 2\nu) + \theta_2(x+y, 2\nu) \theta_2(x-y, 2\nu),$$

$$\theta x \theta y = \theta_3(x+y, 2\nu) \theta_3(x-y, 2\nu) - \theta_2(x+y, 2\nu) \theta_2(x-y, 2\nu),$$

$$\theta_1 x \theta_1 y = \theta_3(x+y, 2\nu) \theta_2(x-y, 2\nu) - \theta_2(x+y, 2\nu) \theta_3(x-y, 2\nu),$$

$$\theta_2 x \theta_2 y = \theta_2(x+y, 2\nu) \theta_3(x-y, 2\nu) + \theta_3(x+y, 2\nu) \theta_2(x-y, 2\nu).$$

I need hardly point out the close analogy between these and the ordinary trigonometrical formulæ.

From these formulæ are easily deduced the following:—

$$\theta \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_3 x \theta_3 y - \theta_2 x \theta_2 y \quad . \quad . \quad (1)$$

$$\theta_1 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_1 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_3 x \theta_3 y - \theta_2 x \theta_2 y \quad . \quad . \quad (2)$$

$$\theta_2 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_2 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_3 x \theta_3 y + \theta_2 x \theta_2 y \quad . \quad . \quad (3)$$

$$\theta_3 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_3 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_3 x \theta_3 y + \theta_2 x \theta_2 y \quad . \quad . \quad (4)$$

$$\theta \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_3 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta x \theta y + \theta_1 x \theta_1 y \quad . \quad . \quad (5)$$

$$\theta_1 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_2 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_1 x \theta y + \theta x \theta_1 y \quad . \quad . \quad (6)$$

$$\theta_2 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta_1 \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta_1 x \theta y - \theta x \theta_1 y \quad . \quad . \quad (7)$$

$$\theta_3 \left\{ \frac{1}{2}(x+y), \frac{1}{2}\nu \right\} \theta \left\{ \frac{1}{2}(x-y), \frac{1}{2}\nu \right\} = \theta x \theta y - \theta_1 x \theta_1 y \quad . \quad . \quad (8)$$

$$2\theta(x+y, 2\nu) \theta(x-y, 2\nu) = \theta x \theta y + \theta_3 x \theta_3 y \quad . \quad . \quad (9)$$

$$2\theta_1(x+y, 2\nu) \theta_1(x-y, 2\nu) = \theta x \theta_3 y - \theta_3 x \theta y \quad . \quad . \quad (10)$$

$$2\theta_2(x+y, 2\nu) \theta_2(x-y, 2\nu) = \theta_3 x \theta_3 y - \theta x \theta y \quad . \quad . \quad (11)$$

$$2\theta_3(x+y, 2\nu) \theta_3(x-y, 2\nu) = \theta_3 x \theta_3 y + \theta x \theta y \quad . \quad . \quad (12)$$

These are taken as fundamental formulæ by Schellbach, and the following four groups deduced from them:—

$$\left. \begin{aligned} \theta_1 \theta_{3,1'} &= \theta_1(o, 2r) \theta_1(2c, 2r), \\ \theta_{1'} \theta_{3,1'} &= \theta_1(o, 2r) \theta_1(2c, 2r), \\ \theta_1 \theta_{1',1'} &= \frac{1}{2} \theta_2(o, \frac{1}{2}r) \theta_1(c, \frac{1}{2}r), \\ \theta_{1'} \theta_{1',1'} &= \frac{1}{2} \theta_2(o, \frac{1}{2}r) \theta_1(c, \frac{1}{2}r). \end{aligned} \right\} \dots \dots \dots (\alpha)$$

$$\left. \begin{aligned} \theta(o) \theta_3(o) &= \theta_1(\frac{1}{2}\pi, \frac{1}{2}r)^2 = \theta_2(\frac{1}{2}\pi, \frac{1}{2}r), \\ \theta(o) \theta_3(o) &= \theta_1(o, 2r)^2 = \theta_1(\frac{1}{2}\pi, \frac{1}{2}r)^2, \\ \theta_2(o) \theta_3(o) &= \frac{1}{2} \theta_2(o, \frac{1}{2}r)^2. \end{aligned} \right\} \dots \dots \dots (\beta)$$

$$\left. \begin{aligned} h\omega^2 h x^2 - g\omega^2 g x^2 &= 1, \\ h\omega^2 f x^2 + g\omega^2 = g\omega^2, \\ g\omega^2 f x^2 + h x^2 &= h\omega^2. \end{aligned} \right\} \dots \dots \dots (\gamma)$$

From (5) and (8), using the first of equations (σ), we have at once

$$\left. \begin{aligned} \theta\omega^2 \cdot \frac{\theta_1(x+y) \theta_1(x-y)}{\theta_1 x^2 \theta y^2} &= 1 - f x^2 f y^2, \\ \theta\omega^2 \cdot \frac{\theta_1(x+y) \theta_1(x-y)}{\theta_1 x^2 \theta y^2} &= -f x^2 - f y^2, \\ \theta_2\omega^2 \cdot \frac{\theta_1(x+y) \theta_1(x-y)}{\theta_1 x^2 \theta y^2} &= h x^2 h y^2 - 1, \\ \theta_2\omega^2 \cdot \frac{\theta_1(x+y) \theta_1(x-y)}{\theta_1 x^2 \theta y^2} &= 1 + g x^2 g y^2. \end{aligned} \right\} \dots \dots \dots (\epsilon)$$

and similarly

Several of these methods and formulæ appear to be due to Krusemark.

Section 9.—The following formulæ are derived by multiplication from (1) . . . (12) of last section:—

$$2\theta x \theta_2 x \theta y \theta_2 y = \theta\omega \theta_2\omega \{ \theta(x+y) \theta_2(x-y) + \theta(x-y) \theta_2(x+y) \} \dots (1)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_3\omega \{ \theta(x+y) \theta_3(x-y) - \theta(x-y) \theta_3(x+y) \} \dots (2)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_3\omega \{ \theta_1(x+y) \theta_3(x-y) + \theta_1(x-y) \theta_3(x+y) \} \dots (3)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_3\omega \{ \theta_1(x+y) \theta_3(x-y) - \theta_1(x-y) \theta_3(x+y) \} \dots (4)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta_2\omega \theta_3\omega \{ \theta_1(x+y) \theta(x-y) + \theta(x+y) \theta_1(x-y) \} \dots (5)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta_2\omega \theta_3\omega \{ \theta_1(x+y) \theta(x-y) - \theta(x+y) \theta_1(x-y) \} \dots (6)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_1\omega \{ \theta_1(x+y) \theta_2(x-y) + \theta_1(x-y) \theta_2(x+y) \} \dots (7)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_1\omega \{ \theta_1(x+y) \theta_2(x-y) - \theta_1(x-y) \theta_2(x+y) \} \dots (8)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_3\omega \{ \theta_1(x+y) \theta(x-y) + \theta_3(x-y) \theta(x+y) \} \dots (9)$$

$$2\theta_1 x \theta_3 x \theta y \theta_3 y = \theta\omega \theta_3\omega \{ \theta_3(x-y) \theta(x+y) - \theta_3(x+y) \theta(x-y) \} \dots (10)$$

Let

$$2T = 1 - f x^2 f y^2 = \theta\omega^2 \frac{\theta(x+y) \theta(x-y)}{\theta_1 x^2 \theta y^2},$$

then

$$\begin{aligned} T\{f(x+y)+f(x-y)\} &= \frac{\theta_1^2}{2} \cdot \frac{\theta_1(x+y)\theta(x-y)+\theta_1(x-y)\theta(x+y)}{\theta_1^2 y^2} \\ &= \frac{\theta_1^2}{\theta_1' \theta_3'} \cdot \frac{\theta_1 x}{\theta_1'} \cdot \frac{\theta_1 y}{\theta_1'} \cdot \frac{\theta_1 y}{\theta_1'} \end{aligned}$$

by (5), or

$$go\ ho T\{f(x+y)+f(x-y)\} = fx\ gy\ hy \quad . \quad . \quad . \quad (11)$$

In the same way may be derived the following:—

$$go\ ho T\{f(x+y)-f(x-y)\} = fy\ gx\ hx \quad . \quad . \quad . \quad (12)$$

$$go T\{g(x-y)+g(x+y)\} = gx\ gy \quad . \quad . \quad . \quad (13)$$

$$go T\{g(x-y)-g(x+y)\} = fx\ hx\ fy\ hy \quad . \quad . \quad . \quad (14)$$

$$ho T\{h(x-y)+h(x+y)\} = hx\ hy \quad . \quad . \quad . \quad (15)$$

$$ho T\{h(x-y)-h(x+y)\} = fx\ gx\ fy\ gy \quad . \quad . \quad . \quad (16)$$

$$go T\{f(x+y)h(x-y)+f(x-y)h(x+y)\} = fx\ hx\ gy \quad . \quad . \quad (17)$$

$$go T\{f(x+y)h(x-y)-f(x-y)h(x+y)\} = fy\ hy\ gx \quad . \quad . \quad (18)$$

$$ho T\{f(x+y)g(x-y)+f(x-y)g(x+y)\} = fx\ gx\ hy \quad . \quad . \quad (19)$$

$$ho T\{f(x+y)g(x-y)-f(x-y)g(x+y)\} = fy\ gy\ hx \quad . \quad . \quad (20)$$

$$go\ ho T\{g(x+y)h(x-y)+g(x-y)h(x+y)\} = gx\ hx\ gy\ hy \quad . \quad (21)$$

$$go\ ho T\{g(x+y)h(x-y)-g(x-y)h(x+y)\} = fx\ gx\ fy\ gy \quad . \quad (22)$$

From these formulæ the ordinary expressions for the addition and subtraction of elliptic functions may of course be easily deduced.

We also find

$$\left. \begin{aligned} \theta_1' a &= \theta a \theta_3' \theta_3 a, & f' a &= \theta_3' a \theta_3 a, \\ f' x &= \theta a^2 gx\ hx, & g' x &= -\theta_3 a^2 fx\ hx, & h' x &= -\theta_3 a^2 fx\ gx. \end{aligned} \right\} \quad . \quad . \quad (c)$$

It is obvious that from the above the following may be immediately formed by addition, &c. :—

$$\left. \begin{aligned} go\ ho f(x+y) &= \frac{fx\ gy\ hy + fy\ gx\ hx}{1 - f'x' f'y'} \\ &= go^2 \frac{fx\ gx\ hy + fy\ gy\ hx}{gx\ gy + fx\ fy\ hx\ hy} = go^2 \frac{ho^2}{fx\ gy\ hy - fy\ gx\ hx} \left. \begin{aligned} f'x' - f'y' \\ f'x' + f'y' \end{aligned} \right\} \quad . \quad (23) \\ &= \frac{ho^2}{go^2} \frac{fx\ gy\ hx + fy\ gx\ hy}{hx\ hy + fx\ fy\ gx\ gy} \end{aligned}$$

$$\left. \begin{aligned} go\ g(x+y) &= \frac{gx\ gy - fx\ fy\ hx\ hy}{1 - f'x' f'y'} = \frac{hx^2 hy^2 - 1}{gx\ gy + fx\ fy\ hx\ hy} \\ &= go^2 \frac{fx\ gx\ hy - fy\ gy\ hx}{fx\ gy\ hy - fy\ gx\ hx} = \frac{gx\ gy\ hx\ hy - fx\ fy}{hx\ hy + fx\ fy\ gx\ gy} \end{aligned} \right\} \quad . \quad (24)$$

$$\left. \begin{aligned} ho\ h(x+y) &= \frac{hx\ hy - fx\ fy\ gx\ gy}{1 - f'x' f'y'} = \frac{fx\ fy + gx\ gy\ hx\ hy}{gx\ gy + fx\ fy\ hx\ hy} \\ &= ho^2 \frac{fx\ gy\ hx - fy\ gx\ hy}{fx\ gy\ hy - fy\ gx\ hx} = \frac{1 + gx^2 gy^2}{hx\ hy + fx\ fy\ gx\ gy} \end{aligned} \right\} \quad . \quad (25)$$

From these formulæ we may deduce as follows:—

It follows from (23) that

$$\frac{ho}{go} f(x+y) = \frac{fx \cdot gx \cdot hy + fy \cdot gy \cdot hx}{gx \cdot gy + fx \cdot fy \cdot hx \cdot hy}.$$

Hence

$$\frac{go - ho f(x+y)}{go + ho f(x+y)} = \frac{(gy - fx \cdot hy)(gx - hx \cdot fy)}{(gy + fx \cdot hy)(gx + hx \cdot fy)}.$$

But from the identical equation

$$\begin{aligned} go^2 - ho^2 \cdot fx^2 + (go^2 \cdot fx^2 - ho^2) \cdot fy^2 \\ = go^2 - ho^2 \cdot fy^2 + fx^2 (go^2 \cdot fy^2 - ho^2) \end{aligned}$$

we obtain from Section 8 (γ)

$$gx^2 - ha^2 \cdot fy^2 = gy^2 - fx^2 \cdot hy^2,$$

or

$$\frac{gx - hx \cdot fy}{gy + fx \cdot hy} = \frac{gy - fx \cdot hy}{gx + hx \cdot fy},$$

and hence substituting

$$\sqrt{\frac{go - ho f(x+y)}{go + ho f(x+y)}} = \frac{gx - hx \cdot fy}{gy + fx \cdot hy} = \frac{gy - fx \cdot hy}{gx + hx \cdot fy},$$

and similarly

$$\begin{aligned} \sqrt{\frac{go - g(x+y)}{go + g(x+y)}} &= \frac{fx \cdot hy + hx \cdot fy}{gy + gx} = \frac{gy - gx}{fx \cdot hy + hx \cdot fy}, \\ \sqrt{\frac{ho - h(x+y)}{ho + h(x+y)}} &= \frac{fx \cdot gy + fy \cdot gx}{hy + hx} = \frac{hy - hx}{fx \cdot gy - gx \cdot fy}. \end{aligned}$$

Section 10.—We now come to an entirely distinct series of theorems, which constitute the most important and interesting addition which has been made to this division of our subject since the publication of the 'Fundamenta Nova.'

It is known that the decomposition of algebraical fractions leads to the following proposition :—

$$\begin{aligned} \frac{\sin(x-a) \sin(x-b)}{\sin(x-a) \sin(x-\beta) \sin(x-\gamma)} &= \frac{\sin(a-\alpha) \sin(a-b)}{\sin(a-\beta) \sin(a-\gamma) \sin(x-\alpha)} \cdot 1 \\ + \frac{\sin(\beta-a) \sin(\beta-b)}{\sin(\beta-\alpha) \sin(\beta-\gamma)} \cdot \frac{1}{\sin(x-\beta)} &+ \frac{\sin(\gamma-a) \sin(\gamma-b)}{\sin(\gamma-\alpha) \sin(\gamma-\beta) \sin(x-\gamma)} \cdot 1 \end{aligned}$$

Similar reasoning, when applied to the expression

$$F(x) = \frac{\theta_1(\lambda-x) \theta_1(\mu-x) \theta_1(\rho-x)}{\theta_1(\alpha-x) \theta_1(\beta-x) \theta_1(\gamma-x)},$$

leads to the theorem

$$\begin{aligned} F(x) &= \frac{\theta_1(\lambda-\alpha) \theta_1(\mu-\alpha) \theta_1(\rho-\alpha)}{\theta_1(\beta-\alpha) \theta_1(\gamma-\alpha)} \sum_{-\infty}^{\infty} \frac{q^n \{e^{(2n\delta+\alpha)i}\}}{\sin(\alpha-x+ni)} \\ &+ \frac{\theta_1(\lambda-\beta) \theta_1(\mu-\beta) \theta_1(\rho-\beta)}{\theta_1(\alpha-\beta) \theta_1(\gamma-\beta)} \sum_{-\infty}^{\infty} \frac{q^n \{e^{(2n\delta+\beta)i}\}}{\sin(\beta-x+ni)} \\ &+ \frac{\theta_1(\lambda-\gamma) \theta_1(\mu-\gamma) \theta_1(\rho-\gamma)}{\theta_1(\alpha-\gamma) \theta_1(\beta-\gamma)} \sum_{-\infty}^{\infty} \frac{q^n \{e^{(2n\delta+\gamma)i}\}}{\sin(\gamma-x+ni)} \end{aligned} \quad (A)$$

where

$$\delta = \lambda + \mu + \rho - \alpha - \beta - \gamma.$$

The reader will find this important theorem, which appears to be due to Richelot, fully demonstrated in Schellbach. If we put $\mu = \beta$ and $\rho = \gamma$ in this equation and at the same time put y for $\lambda - \alpha$, and x for $\alpha - \alpha$, we have

$$\theta_1' o \cdot \frac{\theta_1(x+y)}{\theta_1 x \theta_1 y} = \sum_{-\infty}^{\infty} \frac{q^{s^2} e^{(x+2sy)i}}{\sin(x+syi)} \quad \dots \quad (1)$$

putting in this $x = \frac{1}{2} \pi i$ for x and $y = \frac{1}{2} \pi i$ for y , we have

$$\theta_1' o \cdot \frac{\theta_1(x+y)}{\theta_1 x \theta_1 y} = \sum_{-\infty}^{\infty} \frac{e^{(2s-1)yi}}{\sin(x+(s-\frac{1}{2})\pi i)} \quad \dots \quad (2)$$

and similarly

$$\theta_1' o \cdot \frac{\theta_2(x+y)}{\theta_1 x \theta_2 y} = \sum_{-\infty}^{\infty} \frac{e^{2syi}}{-x \sin(x+syi)} \quad \dots \quad (3)$$

$$\theta_1' o \cdot \frac{\theta_3(x+y)}{\theta_2 x \theta_3 y} = \sum_{-\infty}^{\infty} \frac{e^{2syi}}{-x \cos(x+syi)} \quad \dots \quad (4)$$

$$\theta_1' o \cdot \frac{\theta_2(x+y)}{\theta_1 x \theta_2 y} = \sum_{-\infty}^{\infty} \frac{e^{(2s-1)yi}}{-x \cos(x+(s-\frac{1}{2})\pi i)} \quad \dots \quad (5)$$

$$\theta_1' o \cdot \frac{\theta_1(x+y)}{\theta_1 x \theta_3 y} = \sum_{-\infty}^{\infty} \frac{(-1)^s e^{2syi}}{\sin(x+syi)} \quad \dots \quad (6)$$

$$\theta_1' o \cdot \frac{\theta_2(x+y)}{\theta_2 x \theta_3 y} = \sum_{-\infty}^{\infty} \frac{(-1)^s e^{2syi}}{\cos(x+syi)} \quad \dots \quad (7)$$

$$\theta_1' o \cdot \frac{\theta_1(x+y)}{\theta_1 x \theta_3 y} = i \sum_{-\infty}^{\infty} \frac{(-1)^s e^{(2s-1)yi}}{\cos(x+(s-\frac{1}{2})\pi i)} \quad \dots \quad (8)$$

$$\theta_1' o \cdot \frac{\theta_2(x+y)}{\theta_1 x \theta_2 y} = \sum_{-\infty}^{\infty} \frac{(-1)^s q^s e^{(x+2sy)i}}{\sin(x+syi)} \quad \dots \quad (9)$$

$$\theta_1' o \cdot \frac{\theta_1(x+y)}{\theta_2 x \theta_3 y} = -i \sum_{-\infty}^{\infty} \frac{(-1)^s q^s e^{(x+2sy)i}}{\cos(x+syi)} \quad \dots \quad (10)$$

From these important theorems the series given by Jacobi in his memoir "Sur la Rotation d'un Corps" are easily deduced. If we put $y=0$ in series (2) and reduce, we obtain

$$\theta_1' o \theta_3 o f x = 4 \sin x \sum_{n=0}^{\infty} \frac{q^{n^2} (1+q^{2n+1})}{1-2q^{2n+1} \cos 2x + q^{4n+2}}$$

and by similar means pointed out by Schellbach :

$$\theta_1' o \theta_2 o g x = 4 \cos x \sum_{n=0}^{\infty} \frac{(-1)^n q^{n^2} (1+q^{2n+1})}{1-2q^{2n+1} \cos 2x + q^{4n+2}}$$

$$\theta_1' o \theta_3 o h x = \theta_1' o^2 - 8 \sin^2 x \sum_{n=0}^{\infty} \frac{(-1)^n q^{2n+1} (1+q^{2n+1})}{(1-q^{2n+1})(1-2q^{2n+1} \cos 2x + q^{4n+2})}$$

$$\theta_1' o \theta_2 o \frac{f'x}{f'x} = \cotan x + 4 \sin 2x \sum_{n=0}^{\infty} \frac{(-1)^n q^{n^2}}{1-2q^{2n} \cos 2x + q^{4n}}$$

$$\theta_1' o \theta_3 o \frac{h'x}{f'x} = \frac{1}{\sin x} + 4 \sin x \sum_{n=0}^{\infty} \frac{(-1)^n q^n (1+q^{2n})}{1-2q^{2n} \cos 2x + q^{4n}}$$

$$\begin{aligned}
\theta_2 o \theta_3 o \frac{1}{fx} &= \frac{1}{\sin x} + 4 \sin x \Sigma_1^\infty \frac{q^x(1+q^{2x})}{1+2q^{2x} \cos 2x + q^{4x}}, \\
o o \theta_3 o \frac{fx}{gx} &= \tan x + 4 \sin 2x \Sigma_1^\infty \frac{(-1)^s q^{2s}}{1+2q^{2s} \cos 2x + q^{4s}}, \\
\theta_2 o \theta_3 o \frac{hx}{gx} &= \frac{1}{\cos x} + 4 \cos x \Sigma_1^\infty \frac{q^x(1+q^{2x})}{1+2q^{2x} \cos 2x + q^{4x}}, \\
\theta o \theta_2 o \frac{1}{gx} &= \frac{1}{\cos x} + 4 \cos x \Sigma_1^\infty \frac{(-1)^s q^s(1+q^{2s})}{1+2q^{2s} \cos 2x + q^{4s}}, \\
\theta o \theta_2 o \frac{fx}{hx} &= 4 \cos x \Sigma_0^\infty \frac{(-1)^s q^{s-\frac{1}{2}}(1+q^{2s-1})}{1+2q^{2s-1} \cos 2x + q^{4s-2}}, \\
\theta_2 o \theta_3 o \frac{gx}{hx} &= 4 \cos x \Sigma_0^\infty \frac{q^{s-\frac{1}{2}}(1+q^{2s-1})}{1+2q^{2s-1} \cos 2x + q^{4s-2}}.
\end{aligned}$$

The reader will perceive that these series essentially differ from those in the 'Fundamenta Nova.' The series given in the 'Fundamenta' may be easily deduced from formulæ (1) . . . (10). As, however, my object is to exhibit the progress which the theory of elliptic functions has recently made, I carefully abstain from writing down any series which are given in Jacobi's great work.

Section 11.—We now return to theorem A of last section. Transforming the series in the second member of this equation by means of expression (1) in last section: since

$$\Sigma_{-\infty}^\infty \frac{q^s e^{2syi}}{\sin(x+svi)} = \theta_1'(o) e^{-ai} \frac{\theta_1(x+y)}{\theta_1 x \theta_1 y},$$

whence

$$\Sigma_{-\infty}^\infty \frac{q^s e^{2s\delta i}}{\sin(\alpha-x+svi)} = \theta_1'(o) e^{(x-\alpha)i} \frac{\theta_1(\alpha-x+\delta)}{\theta_1(\alpha-x) \theta_1 \delta},$$

and similarly for

$$\Sigma_{-\infty}^\infty \frac{q^s e^{2s\delta i}}{\sin(\beta-x+svi)} \quad \text{and} \quad \Sigma_{-\infty}^\infty \frac{q^s e^{2s\delta i}}{\sin(\gamma-x+svi)},$$

we obtain

$$\begin{aligned}
\theta_1 \delta F(x) &= \frac{\theta_1(\lambda-\alpha) \theta_1(\mu-\alpha) \theta_1(\rho-\alpha)}{\theta_1(\beta-\alpha) \theta_1(\gamma-\alpha)} \cdot \frac{\theta_1(\alpha-x+\delta)}{\theta_1(\alpha-x)} \\
&+ \frac{\theta_1(\lambda-\beta) \theta_1(\mu-\beta) \theta_1(\rho-\beta)}{\theta_1(\alpha-\beta) \theta_1(\gamma-\beta)} \cdot \frac{\theta_1(\beta-x+\delta)}{\theta_1(\beta-x)} \\
&+ \frac{\theta_1(\lambda-\gamma) \theta_1(\mu-\gamma) \theta_1(\rho-\gamma)}{\theta_1(\alpha-\gamma) \theta_1(\beta-\gamma)} \cdot \frac{\theta_1(\gamma-x+\delta)}{\theta_1(\gamma-x)}.
\end{aligned}$$

For $x=0$ we have

$$\left. \begin{aligned}
\frac{\theta_1 \lambda \theta_1 \mu \theta_1 \rho}{\theta_1 \alpha \theta_1 \beta \theta_1 \gamma} &= \frac{\theta_1(\alpha+\delta)}{\theta_1 \alpha} \cdot \frac{\theta_1(\lambda-\alpha) \theta_1(\mu-\alpha) \theta_1(\rho-\alpha)}{\theta_1 \alpha \theta_1(\beta-\alpha) \theta_1 \gamma - \alpha} \\
&+ \frac{\theta_1(\beta+\delta)}{\theta_1 \beta} \cdot \frac{\theta_1(\lambda-\beta) \theta_1(\mu-\beta) \theta_1(\rho-\beta)}{\theta_1 \beta \theta_1(\alpha-\beta) \theta_1(\gamma-\beta)} \\
&+ \frac{\theta_1(\gamma+\delta)}{\theta_1 \gamma} \cdot \frac{\theta_1(\lambda-\gamma) \theta_1(\mu-\gamma) \theta_1(\rho-\gamma)}{\theta_1 \gamma \theta_1(\alpha-\gamma) \theta_1(\beta-\gamma)},
\end{aligned} \right\} \dots (1)$$

where, replacing α, β, γ by $\alpha + \frac{1}{2}\nu i, \beta + \frac{1}{2}\nu i, \gamma + \frac{1}{2}\nu i$, we have

$$\left. \begin{aligned} \frac{\theta_1 \lambda \theta_1 \mu \theta_1 \rho}{\theta \alpha \theta_1 \beta \theta \gamma} &= \frac{\theta_1(\alpha + \delta)}{\theta \delta} \cdot \frac{\theta(\lambda - \alpha) \theta(\mu - \alpha) \theta(\rho - \alpha)}{\theta \alpha \theta_1(\beta - \alpha) \theta_1(\gamma - \alpha)} \\ &+ \frac{\theta_1(\beta + \delta)}{\theta \delta} \cdot \frac{\theta(\lambda - \beta) \theta(\mu - \beta) \theta(\rho - \beta)}{\theta \beta \theta_1(\alpha - \beta) \theta_1(\gamma - \beta)} \\ &+ \frac{\theta_1(\gamma + \delta)}{\theta \delta} \cdot \frac{\theta(\lambda - \gamma) \theta(\mu - \gamma) \theta(\rho - \gamma)}{\theta \gamma \theta_1(\alpha - \gamma) \theta_1(\beta - \gamma)} \end{aligned} \right\} \dots \dots (2)$$

Putting $\rho = \gamma$ in (1), we have

$$\frac{\theta_1 \lambda \theta_1 \mu}{\theta_1 \alpha \theta_1 \beta} = \frac{\theta_1(\alpha + \delta)}{\theta_1 \delta} \cdot \frac{\theta_1(\lambda - \alpha) \theta_1(\mu - \alpha)}{\theta_1 \alpha \theta_1(\beta - \alpha)} + \frac{\theta_1(\beta + \delta)}{\theta_1 \delta} \cdot \frac{\theta_1(\lambda - \beta) \theta_1(\mu - \beta)}{\theta_1 \beta \theta_1(\alpha - \beta)},$$

and (2) replacing λ by $\alpha + \frac{1}{2}\nu i, \mu$ by λ , and γ by α , we have

$$\frac{\theta_1 \lambda \theta_1 \mu}{\theta \alpha \theta_1 \beta} = \frac{\theta(\alpha + \delta)}{\theta_1 \delta} \cdot \frac{\theta(\lambda - \alpha) \theta(\mu - \alpha)}{\theta \alpha \theta_1 \beta - \alpha} + \frac{\theta(\beta + \delta)}{\theta_1 \delta} \cdot \frac{\theta(\lambda - \beta) \theta(\rho - \beta)}{\theta \beta \theta_1(\alpha - \beta)},$$

where in each formula $\delta = \lambda + \mu - \alpha - \beta$.

Putting

$$\lambda - \alpha = a, \quad \beta = b, \quad \mu - \alpha = c, \quad \lambda + \mu - \beta = d,$$

and then

$$2s = a + b + c + d, \quad 2\sigma = a + b + c - d,$$

these formulæ become

$$\begin{aligned} \theta_1 a \theta_1 b \theta_1 c \theta_1 d &= \theta_1 \sigma \theta_1(s - a) \theta_1(s - b) \theta_1(s - c) - \theta_1 s \theta_1(\sigma - a) \theta_1(\sigma - b) \theta_1(\sigma - c), \\ \theta a \theta b \theta c \theta d &= \theta_1 \sigma \theta_1(s - a) \theta_1(s - b) \theta_1(s - c) + \theta s \theta(\sigma - a) \theta(\sigma - b) \theta(\sigma - c). \end{aligned}$$

From these it has been fully shown by Schellbach that the following formulæ may be derived, which were given by Jacobi under another shape in the thirty-ninth volume of Crelle:—

$$\begin{aligned} ho \, hx &= hy \, h(x+y) + go \, g'x \, fy \, f(x+y), \\ ho \, hy &= hx \, h(x+y) + go \, f'x \, gy \, f(x+y), \\ ho \, g'x \, fy &= go \, h'x \, f(x+y) - f'x \, gy \, h(x+y), \\ ho \, gy \, f'x &= go \, hy \, f(x+y) - g'x \, f'y \, h(x+y), \\ ho \, g'x \, f(x+y) &= f'x \, hy \, g(x+y) + go \, h'x \, f'y, \\ ho \, gy \, f(x+y) &= h'x \, f'y \, g(x+y) + go \, f'x \, hy, \\ ho \, h(x+y) &= h'x \, hy - go \, f'x \, fy \, g(x+y), \\ ho \, f'x \, g(x+y) &= g'x \, hy \, f(x+y) - go \, fy \, h(x+y), \\ ho \, fy \, g(x+y) &= h'x \, gy \, f(x+y) - go \, f'x \, h(x+y), \\ ho \, f'x \, hy \, f(x+y) &= go \, gy - g'x \, g(x+y), \\ ho \, h'x \, fy \, f(x+y) &= go \, g'x - gy \, g(x+y), \\ ho \, g'x \, hy \, g(x+y) &= go \, gy \, h'x \, h(x+y) - f'x \, f(x+y), \\ ho \, h'x \, gy \, g(x+y) &= go \, g'x \, hy \, h(x+y) - f'y \, f(x+y), \\ ho \, f'x \, fy \, h(x+y) &= g'x \, gy - go \, g(x+y), \\ ho \, g'x \, gy \, h(x+y) &= f'x \, f'y + go \, h'x \, hy \, g(x+y), \\ ho \, h'x \, hy \, h(x+y) &= 1 + go \, g'x \, gy \, g(x+y). \end{aligned}$$

Section 12.—We now proceed to give certain formulæ relative to the differential coefficients of the logarithms of functions θ , essentially the same functions, be it remembered, as those which Jacobi writes with the letter Z .

Schellbach's four fundamental equations are as follows:

$$l'\theta_1x - l''\theta_1y = \theta_2\theta^2\theta_3\theta^2 \left(\frac{1}{fy^2} - \frac{1}{fx^2} \right) \quad . \quad . \quad . \quad (1)$$

$$l''\theta_1x - l''\theta_1y = \theta_2\theta^2\theta_3\theta^2 \left(fgy^2 - \frac{1}{2}fx^2 \right) \quad . \quad . \quad . \quad (2)$$

$$l'\theta_2x - l''\theta_2y = \theta\theta^2\theta_2\theta^2 \left(\frac{1}{gy^2} - \frac{1}{gx^2} \right) \quad . \quad . \quad . \quad (3)$$

$$l''\theta_3x - l''\theta_3y = \theta\theta^2\theta_3\theta^2 \left(\frac{1}{hy^2} - \frac{1}{hx^2} \right) \quad . \quad . \quad . \quad (4)$$

Of these, Schellbach has fully proved the first. The second is immediately derived from the first by putting $x = \frac{1}{2}\pi i$ for x , and $y = \frac{1}{2}\pi i$ for y . The third may be found by putting in the second $x + \frac{\pi}{2} - \frac{1}{2}\pi i$ for x , and $y + \frac{\pi}{2} - \frac{1}{2}\pi i$ for y . We thus obtain

$$\begin{aligned} l'\theta_2x - l''\theta_2y &= \theta_2\theta^2\theta_3\theta^2 \left\{ f^2 \left(y + \frac{\pi}{2} - \frac{1}{2}\pi i \right) - f^2 \left(x + \frac{\pi}{2} - \frac{1}{2}\pi i \right) \right\} \\ &= \theta_2\theta^2\theta_3\theta^2 \left\{ \frac{hy^2}{gy^2} - \frac{hx^2}{gx^2} \right\} = \theta_2\theta^2\theta_3\theta^2 \left\{ \frac{1 + g\theta^2gy}{h\theta^2gy} - \frac{1 + g\theta^2gx}{h\theta^2gx} \right\} \\ &= \theta\theta^2\theta_2\theta^2 \left\{ \frac{1}{gy^2} - \frac{1}{gx^2} \right\}. \end{aligned}$$

Formula (4) may of course be demonstrated in the same way.

Putting $y = \frac{1}{2}\pi i$ for y in the second of these formulæ, we have

$$l'\theta_1x - l''\theta_1y = \theta_2\theta^2\theta_3\theta^2 \left(\frac{1}{fy^2} - \frac{1}{fx^2} \right) \quad . \quad . \quad . \quad (5)$$

also we find

$$l''\theta_1x - l''\theta_1y = \theta\theta^2\theta_2\theta^2 \left(\frac{1}{gy^2} + \frac{1}{gx^2} \right) \quad . \quad . \quad . \quad (6)$$

$$l''\theta_3x - l''\theta_3y = \theta\theta^2\theta_3\theta^2 \left(\frac{1}{hy^2} - \frac{1}{hx^2} \right) \quad . \quad . \quad . \quad (7)$$

Let $x=y$ in these formulæ, and we have

$$l'f(x) = \theta_2\theta^2\theta_3\theta^2 \left(\frac{1}{fx^2} - \frac{1}{fx^2} \right) \quad . \quad . \quad . \quad (8)$$

$$l''gx = \theta\theta^2\theta_2\theta^2 \left(\frac{1}{gx^2} + \frac{1}{gx^2} \right) \quad . \quad . \quad . \quad (9)$$

$$l''hx = -\theta\theta^2\theta_3\theta^2 \left(\frac{1}{hx^2} - \frac{1}{hx^2} \right) \quad . \quad . \quad . \quad (10)$$

From these Schellbach deduces the following series of formulæ by easy methods:—

$$\left. \begin{aligned}
 \theta_2 \theta^2 \theta_3 \theta^2 f x^2 &= l'' \theta_2 \theta - l'' \theta_3 x, \\
 \theta \theta^2 \theta_2 \theta^2 g x^2 &= l'' \theta_2 x - l'' \theta_3 \theta, \\
 \theta \theta^2 \theta_3 \theta^2 h x^2 &= l'' \theta_3 x - l'' \theta_2 \theta,
 \end{aligned} \right\}$$

$$\left. \begin{aligned}
 \theta_2 \theta^2 \theta_3 \theta^2 \frac{1}{f x^2} &= l'' \theta_2 \theta - l'' \theta_3 x, \\
 \theta \theta^2 \theta_2 \theta^2 \frac{1}{g x^2} &= l'' \theta_2 x - l'' \theta_3 \theta, \\
 \theta \theta^2 \theta_3 \theta^2 \frac{1}{h x^2} &= l'' \theta_3 x - l'' \theta_2 \theta,
 \end{aligned} \right\}$$

$$\left. \begin{aligned}
 \theta_2 \theta^2 \theta_3 \theta^2 \frac{g x^2}{h x^2} &= l'' \theta_2 \theta - l'' \theta_3 x, & \theta_2 \theta^2 \theta_3 \theta^2 \frac{h x^2}{g x^2} &= l'' \theta_2 \theta - l'' \theta_3 x, \\
 \theta \theta^2 \theta_2 \theta^2 \frac{f x^2}{h x^2} &= l'' \theta_2 x - l'' \theta_3 \theta, & \theta \theta^2 \theta_2 \theta^2 \frac{h x^2}{f x^2} &= l'' \theta_2 x - l'' \theta_3 \theta, \\
 \theta \theta^2 \theta_3 \theta^2 \frac{g x^2}{f x^2} &= l'' \theta_3 \theta - l'' \theta_2 x, & \theta \theta^2 \theta_3 \theta^2 \frac{f x^2}{g x^2} &= l'' \theta_3 \theta - l'' \theta_2 x.
 \end{aligned} \right\}$$

We now come to a group of an entirely different kind,

$$l''(\theta_2 \theta_3 x) + (l' f x)^2 = l''(\theta_2 \theta_3 \theta),$$

$$l''(\theta_2 x \theta_3 x) + (l' g x)^2 = l''(\theta_2 \theta_3 \theta),$$

$$l''(\theta_3 x \theta_2 x) + (l' h x)^2 = l''(\theta_2 \theta_3 \theta).$$

These formulæ were discovered by Meyer, who gave them, in the thirty-seventh volume of Crelle's Journal, under the following form:—

$$\frac{\theta' x}{\theta x} + \frac{\theta'' \left(x + \frac{\pi}{2}\right)}{\theta \left(x + \frac{\pi}{2}\right)} - 2 \frac{\theta' x \theta \left(x + \frac{\pi}{2}\right)}{\theta x \theta \left(x + \frac{\pi}{2}\right)} = \frac{\theta'' \frac{\pi}{2}}{\theta \frac{\pi}{2}} + \frac{\theta''(0)}{\theta(0)},$$

$$\frac{\theta' x}{\theta x} + \frac{\Pi' x}{\Pi x} - 2 \frac{\theta' x \Pi' x}{\theta x \Pi x} = \frac{\Pi' \frac{\pi}{2}}{\Pi \frac{\pi}{2}} + \frac{\theta'' \frac{\pi}{2}}{\theta \frac{\pi}{2}},$$

$$\frac{\theta' x}{\theta x} + \frac{\Pi'' \left(x + \frac{\pi}{2}\right)}{\Pi \left(x + \frac{\pi}{2}\right)} - 2 \frac{\theta' x \Pi'' \left(x + \frac{\pi}{2}\right)}{\theta x \Pi \left(x + \frac{\pi}{2}\right)} = \frac{\Pi'' \frac{\pi}{2}}{\Pi \frac{\pi}{2}} + \frac{\theta'' 0}{\theta 0},$$

where the reader may see them fully demonstrated from the 'Fundamenta Nova' of Jacobi.

They are applied by him in a memoir in the fifty-sixth volume of Crelle, entitled "Ueber die rationalen Verbindungen der elliptischen Transcendenten," to prove that if $U = \frac{\Delta \phi^r \sin \phi^s \cos \phi^t}{(1 + a \sin \phi)^m}$, where a is supposed a function of q , then $\Sigma x \cdot U$ can be determined from U by simple integration with respect to (x) only.

In the course of the investigation he gives the following expressions:—

$$\frac{dk}{dq} = \frac{k}{2q} \cdot \left\{ \frac{2Kk'}{\pi} \right\}^2, \quad \frac{dk'}{dq} = -\frac{k'}{2q} \left\{ \frac{2Kk}{\pi} \right\}^2.$$

I shall conclude this portion of my work by a remark of Riemann, that if $\S u = \sum_{n=-\infty}^{\infty} e^{an^2+2nu}$, then if (r) and (s) be any two positive or negative integers, $\S u$ vanishes if $u = (r + \frac{1}{2})\pi i + (s + \frac{1}{2})\pi$. In mentioning the name of Riemann, I am glad to take the earliest opportunity of paying a humble tribute to the memory of one of the most illustrious mathematicians which either his country or the world has ever seen.

Report on Mineral Veins in Carboniferous Limestone and their Organic Contents. By CHARLES MOORE, F.G.S.

A CAREFUL consideration of the phenomena attending mineral veins needs the aid of the physical geologist, the electrician, the chemist, the mineralogist, and also, as I shall presently show, that of the paleontologist, in order to arrive at correct conclusions respecting their age, the materials they contain, from whence those materials were derived, and the time when they were subsequently deposited in them. Unfortunately I do not profess to have any knowledge of some of these sciences, and the conclusions to which I have arrived will therefore be based upon general observations, such as could be given to the physical conditions of various mineral districts, and the manner under which some of the veins have been formed and refilled.

There are few subjects connected with the physical history of our globe which have presented greater difficulties in their elucidation, and few the study of which have, up to this time, had less satisfactory or certain results than the laws which have regulated our mineral deposits, the views entertained having the wide divergence between a Plutonic and a Neptunian origin for our minerals; and although the tendency of opinion is probably in the latter direction, it may be almost said that at this time there is no fixed view on a subject of such great economic importance.

The opinions of various authors may be chiefly classed under the heads of "sublimation" and "segregation," whilst those of Werner, that the minerals in the veins have been derived from the waters of the ocean, and those recently propounded by Mr. Wallace, that they owe their presence to atmospheric causes and conditions in connexion with segregation, deserve attention.

1st. By sublimation is meant that all our minerals have been entirely derived from the passage upwards of certain vapours yielding the minerals through the veins, which have been vents from the heated interior of the earth.

2nd. By segregation, that the minerals now found in veins were contemporaneous with, and deposited in very minute quantities in the horizontal strata which now form the walls of the veins, and that by some mode or other they have subsequently been removed from the surrounding rocks and redeposited as they are now found in the veins.

Minerals are only met with in the crust of the earth, in stratified beds, and in mineral veins.

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Under the first condition, it will be very generally admitted that the materials from whence those minerals were derived must have been held in solution in the waters of the ocean at the different periods when the stratified beds containing them were being deposited, and that the lime, the silica, the iron, which will be found more or less abundantly in every formation, must have been, with few if any exceptions, precipitated contemporaneously. Although the ores of copper, tin, lead, and other rarer minerals which are found most frequently in veins may occasionally be detected in stratified beds, it is evident, from the mere traces of them that are obtained over the widest areas and in geological time, that the laws which were necessary to their deposition so abundantly in veins, were in their case to a considerable extent inoperative.

Physical conditions necessary to Mineral Veins.—It is only stating a truism to remark that the rocks in association with which our mineral veins are found are almost entirely of marine origin; that they once formed the bottom of ancient seas, and in their undisturbed conditions were laid down horizontally, and were continuous, and without the enormous rents and fissures which now traverse them in every direction. The mere contraction of the beds during solidification would not be sufficient to account for the phenomena, as in this case the fissures would not pass down continuously to any depth. It appears, therefore, clear that all veins must be due to the elevation or depression of the portion of the earth's crust in which they are found, and that they are younger than or formed subsequently to the consolidation of the rocks enclosing them, their age depending on the period of physical change.

It would be difficult for any one not acquainted with mining operations to realize the enormous forces that have been in operation in different ages to produce the dislocations necessary for the reception of our mineral lodes. To the physical geologist there can be few more remarkable phenomena than mining districts present, or than the study of a well-prepared map of any of our larger districts would show. As an instance, I may mention a map of the Alston district, in Cumberland, prepared by Mr. Wallace, in which it may be seen that, occupying very large areas, there is a complete network of fissures, the same veins being traceable through many miles of country, crossed by others at varying angles. I have also shown this to be the case in the Mendip district*, where the east and west veins in passing parallel with one another through that line of country are repeatedly intersected by cross courses, and to such an extent that numerous examples, especially towards Frome, may be seen in almost every limestone-quarry.

It being admitted that through the volcanic disturbances indicated the fissured character of our rocks has been produced, it will be desirable to consider the influence exercised by the ocean in refilling the veins thus caused.

On examining caverns and fissures of the Carboniferous Limestone which are now open, it can at once be seen, by the honeycombed and worn character of the roofs and sides, that they must at some period have formed channels or passages for large bodies of water. Although in most Carboniferous-limestone districts it is known that "swallet holes" occur, through which the water now passes down and traverses certain lines of open fissures below, which form the natural drainage of the country, the stream sometimes reappearing miles away from whence it entered, still these are excep-

* "Abnormal Conditions of Secondary Deposits," &c., Geol. Journ. Dec. 1867. 1869.

tional cases; the great majority of the open fissures are beyond and without this influence, and it must be obviously impossible, to any great extent, where the fissures have been refilled, that there could be the passage of any considerable bodies of water through them since they have obtained their present elevations, in some instances amounting to several thousand feet above the sea-level. It appears to me, therefore, more probable that the denudation to which they have been subject is due in great measure to the long-continued action of marine currents, whilst the fissures, the upper parts of which afford the most striking evidence of this condition, still remained open beneath the surface of the ocean. This might have been for greatly extended periods, as there is evidence throughout the Mendip and South Wales districts that the Carboniferous Limestones formed the floor of the sea through Triassic, Liassic, and Oolitic times.

After the disturbing influence by which the fissures were caused, their filling up by derived materials, and the time occupied thereby, must have depended upon local causes that were in operation in the several areas in which they occurred. In some instances, where little or no sedimentary matter was being derived from adjoining lands, or where no pre-existing stratified deposits were being denuded, few materials for this purpose would be supplied, and a greater length of time would elapse before the fissures received their vein-stuff, of whatever kind, whilst on the contrary they would more or less speedily have received the deposits with which they are now filled, subject, in either case probably, to a scouring out and occasional modification of the material within their walls.

Contents of Fissures.—In working for various minerals, it is usually found that the more precious contents of the veins are either in vertical strings, in bunches or pockets, or more rarely in flats, and that they form but a very small part of the contents of the fissures. When attention is given to the other materials which form by far the greater bulk of the infilling, it will be found in some instances to be of a very varied character, those even in the same mine being most remarkable. Though in general there might be an agreement in the character of the deposit in the same mineral field or area, when separate districts are examined, the distinction is more marked; often the material brought into the vein is conglomeratic, consisting of both angular and rolled pebbles—in the former case probably derived from the adjacent walls of the vein, or from a source not far removed; in the latter case, which is not an unfrequent one, the pebbles are from rocks not contemporaneous, some of which have therefore a foreign origin, and, either in being brought from a distance or from the subsequent action of the water in the fissure, have been as much rounded as are some of those found in the drifts of our superficial quaternary deposits. The cavernous interstices left in such conglomerates are favourable to the deposition of minerals for which the veins are worked; and where this is not the case, they are usually cemented together by carbonate of lime, quartz, or some other material incident to the infilling.

Still more frequently, in many districts, from forming the great bulk of the infilling, the "dowky" portions, or the clays, of the veins are charged with varying deposits of a sandy nature, with marl or clay, or with a material assuming a variegated or finely conglomeratic character, showing an admixture brought from different sources, or by the denudation of beds of different mineralogical conditions, analogous to stratified deposits when brought together by opposing currents. The variety in the character of the vein-stuff is at times most marked; and there may be obtained from the

same vein samples of "dowks" which, when washed, give almost every conceivable hue of colour, from the most delicate French white to the densest shades of black or indigo, all being due to the different chemical or mineralogical conditions of the matrix. Additional evidence is afforded of the derived nature of the "dowks" by the occasional presence in them of fossil wood. I have found a piece in the Charterhouse Mine, converted into jet, with the cellular portions containing galena; and another example is recorded from the Hudgill Burn Mine, the exterior of which was covered with galena. Whenever in a given area a series of fissures were open at the same time, and subject to the same conditions of deposition, it is quite possible that certain horizons of infilling might be found in them, though, from the peculiar circumstances attending them, their recognition would involve close observation.

Having said thus much of the fissures and their more unprofitable contents, I now proceed to consider the views that have been usually entertained as to the deposition of the minerals therein.

Views of Mineral Deposition.—Next to the one which I shall hereafter suggest of a purely marine origin for the minerals, I believe that of sublimation to have the greatest probability; but there are, I think, many reasons against this supposed cause.

It necessarily involves, what was most likely the fact, that the fissures originally continued downwards until they reached the source of volcanic action, which in some instances must have been seated at an enormous depth. The moment the fissures were opened, of whatever width, if within the influence of the ocean, they must have been filled by its waters, and liable more or less quickly to receive their now varied contents. Their lower depths would naturally be first filled. Where the rents passed through, as must often have been the case, soft and yielding beds, this might often have occurred quickly, in others only after a great lapse of time. Were the doctrine of sublimation true, we ought, I think, to have greater evidence of the continued passage upwards of volcanic fluids, in the very lowest depths, instead, as is most often the case, of finding our minerals high up in the veins, or occurring chiefly on given horizons in them, or even in pockets at their surfaces. It appears to me also that the "dowks" or clays through which so subtle and potent an agent must have been continually passing, charged with its varied minerals, must have shown much greater evidence of its effects than is now seen in them, and that they would more frequently have tended to precipitate the minerals before they could have passed so far upwards in the vein in which they are now more frequently found.

The doctrine of segregation, which at this time appears to have most believers, is, I think, open to greater objection than that of sublimation. Its disciples believe that, subsequently to the movements which have caused the fissures, a process has been going on which even now is collecting the various minerals together towards a fixed point, according to their natural affinities, extracting them from the adjoining rocks, and redepositing them in the veins. This view is purely imaginary and incapable of proof, and seems to me as impossible as the idea I had when a boy, that if you planted a stone, in process of time it might grow into a mountain. There seems to me no possibility how, under this supposition, any mineral can be withdrawn, and necessarily replaced by another totally different, involving a circulatory movement continually in progress in the matrix of some of our most extensive geological formations. Probably, as regards their chemical constituents, there are no more homogeneous rocks than the great series of the

Carboniferous Limestones, the veins of which yield a considerable proportion of our lead, calamine, and iron-ore; and chemical analysis will show that the constituents necessary to the production of these minerals are almost entirely absent from them over the widest areas. The limestones that come nearest in contact with the walls of strong mineral lobes ought, with this view, to yield the best evidence that the minerals have been thus segregated together; but it will be found that they are as free from the minerals that are in the veins as would be samples taken at any distance from the fissures.

Under this head it is desirable I should notice a view lately suggested by Mr. Wallace. This gentleman has lately published an elaborate work on 'The Laws which regulate the Deposition of Ores in Veins,' which, though having special reference to the Alston-Moor district, is proposed by him as a law explaining the ore-deposits in all mineral veins. His work shows an intimate knowledge of the complicated physical details of that extensive mining-region, in which, in opposition to sublimation, he remarks, that all the lead-veins are found most productive where furthest removed from the seat of Plutonic action, the richest deposits being in the upper part of the Carboniferous Limestone where no igneous rocks are found, and that in that district there is nothing to support the theory that lead is due to exhalations from below, or to matter injected in a fluid state among the consolidated sedimentary rocks. Instead of this he states that the more probable cause of the lead-ore at Alston is owing to segregation from, or decomposition of, the rocks which form the walls of the veins where they are found. In adopting the doctrine of segregation, he proposes, for the first time, to combine with it another cause, without which there would be no important deposits of minerals, viz. that of recent hydrous and atmospheric agency. Without the passage of large bodies of water downwards from the surface, derived from the rainfall of the district, and their free circulation in the veins, there would be no conditions favourable to the deposit of minerals; in all cases he states such deposits are found only where fluids most freely percolate the surface and circulate in the veins, and that these conditions only occur where the strata are situated at moderate depths from the surface, and at some considerable distance from the watershed of the mountain; that, combined with electrical action, these agents have been the means of extracting the minerals from the adjoining rocks; that the operation is still in progress, and that all has been accomplished since the Glacial period.

The examination I have given to mineral veins and their contents does not support this view. The chief material of all mineral veins I find to be of marine origin; all the organic contents are fossil, and their precise geological age can be arrived at without much difficulty. Wherever they contain land shells, as on the Mendips, or freshwater shells, which occur in the veins of Alston, and are wide-spread elsewhere, they are also fossil and of contemporaneous age with the other remains*. It is certain from this that the veins received their infilling when within the influence of the ocean, and before their present elevation, since which time, as I have before stated, I doubt if there could be any material alteration in their contents.

But supposing their vein-stuff to be postglacial, and that their deposit had been effected by large bodies of water passing down through them from the surface, ample evidence would have been present of the fact; for in the place of fossil organic remains, which in some instances indicate the exact age of the minerals, there would have been found recent land and freshwater

* See remarks on the presence of Land and Freshwater Shells, p. 369.

shells and plants abundantly. Of this, through a long examination of the contents of mineral veins, I have seen no evidence either in the Alston or any other mining-district.

Postpliocene caverns and fissures have, however, remained open to this time, in many instances, in our Carboniferous-limestone ranges; and although they have been within the influence of, and subject to, the effect suggested by Mr. Wallace, their organic contents consist chiefly of the extinct mammalia of that period, whilst their mineral deposits are confined to the stalactitic and stalagmitic deposits on their roofs and floors which have been slowly accumulating since the postpliocene period.

The Neptunian theory, first advanced by Werner for the origin of minerals, would probably before this have received greater attention but for the other extravagant ideas he connected with it. I shall now offer some suggestions regarding its probable truth.

It appears to me necessary, in the first place, that, for the production of minerals, there should be the following elements or conditions, viz. the presence of the minerals themselves in the waters of the ocean, open fissures communicating therewith, favourable electrical conditions, and time for their precipitation.

It has now been established, without doubt, by the highest chemical authorities, that many of our most important minerals are present in minute quantities in the waters of the ocean. This is admitted by those who believe in segregation, the difference being that they think it was first deposited and afterwards extracted from the parent rock, and redeposited in the veins, rather than originally collected in the veins themselves.

As regards the connexion subsisting between the ocean and the vein-fissures, I believe it will be recognized to be the case that, in the great majority of instances, the different veins come directly to the surface, and wherever a later rock has been deposited, which is only in exceptional cases, covering up the mouth of the vein, there will still be found a break in the sequence of the strata, which might give almost unlimited time for the precipitation of the minerals therein. Wherever systems of veins occur, it is probable there will be found connected therewith an abnormal condition and considerable breaks in the deposition of the rocks. I have shown this to be the case in connexion with the Carboniferous Limestone of the Mendip range, and its continuation through South Wales, in which districts it can be seen that those rocks were, through enormous periods, exposed to the influence of the ocean, possibly forming reef-like barriers around the edges of the carboniferous basin, the fissured veins and floor of this sea-bottom receiving at some periods materials of Rhætic or of Lower or Middle Lias age, whilst an occasional capping of the beds of Inferior Oolite, left in some Carboniferous Limestone trough, now and then cover up the mouths of the veins that had received all their contents prior to its deposition. Some most instructive examples are present in this district, in which it may be seen that whilst there are on the walls of the vein the usual vertical conditions of vein-stuff, such as calc spar, sulphate of barytes, &c., with occasional hematite iron-ore, calamine, and galena, the central portion of the vein is unmistakably of Liasic or Rhætic age. In all such instances there are combined the elements of open fissures communicating with the ocean, and greater or less time in the reception of their contents.

Various Ages of Minerals.—It will be found that minerals generally occur in the outcrops of lines of strata, possibly occupying, to some extent, the same relative positions, as regards the strata by which they are now sur-

rounded, as in earlier times, and that the mineral-bearing rocks formed the floor or backbone on which the later beds were laid down. This is the case with Australian and Californian auriferous regions, the enormous denudation and consequent drifts of Tertiary age in the former case having laid bare the backbone of the auriferous-bearing rock below. I have already shown this to be the case with the Carboniferous Limestones of the west of England and South Wales, where, in connexion with them, veins and pockets of mineral-bearing lias are found. Liassic minerals, again, occur on what is probably a continuation of the same great barrier, which, passing under the south-eastern counties, crosses the channel to France, where they are seen on a floor of granite. The outcrops of some of the limestones of North Wales and the north of England have been exposed to the influence of seas certainly as late as the Coal-measures and the minerals found in the great mining-districts of Cornwall, whether in the killas or the granite itself, are found connected with, or resting upon, a great backbone of the latter rock.

It is also worthy of remark that the conglomerates usually skirting the edge of the limestone, which must long have been subject to the action of the ocean, are large receptacles of iron, calamine, and lead, the veins in which seldom, if ever, pass downwards into the limestone, and which, though open to the ocean, are cut off from sublimation beneath. The fissures in these great lines of submarine mountains must necessarily have been chiefly filled with marine matter, whether mineral or otherwise; sometimes, where the materials were friable, supplied by the walls of the fissure, but perhaps oftener derived. Wherever there has been a rapid filling up of the veins by a homogeneous material, the element of time is excluded, such as with the "clawky" portions of the veins, and in such cases workable minerals are seldom found. The same occurs where there is a sequence of deposition, and stratification follows without a break in natural order. If the above view be correct, it follows that the longer a fissure has been exposed to the influence of the ocean, the greater will be the probability of a larger supply of minerals therein. Where veins have been slowly filled, where they have been cavernous, or by subsequent movements have been opened on several occasions, where they contain conglomeratic infillings, or have been kept open by currents, favourable conditions to deposition occur; and it is a well-known law of mining that, at the junction where veins intersect, rich deposits or pockets of minerals are most usually found, from the fact that at such points there has been a scouring out of the fissures, and a longer time given for precipitation.

Paleontology of Mineral Veins.—The physical views I have suggested are strongly supported by the investigations I have for some time been pursuing regarding the presence of organic remains in mineral veins. During those investigations I have examined materials derived from Carboniferous-limestone veins and fissures from the mining-districts of Wharfedale, Wensleydale, Weardale, Teesdale, Swaledale, Alston Moor, Kewick, North and South Wales, and Somersetshire; and I am much indebted, for the facilities they have afforded me in their several districts, to Lord Bolton and Messrs. Wallace, Walton, Eddy, Bainbridge, Cain, Peart, Wasley, and Sopwith.

It is remarkable, considering the enormous mine-workings and the quantity of vein-stuff brought to the surface in every part of the world, that so few notices of the presence of fossils in them should have occurred. In his 'Elements of Geology,' p. 762, Sir Charles Lyell mentions that M. Virlet had found a *Crypsina* in a lead-mine near Semur in France, and that a madrepore had been seen in a compact vein of cinnabar in Hungary, the pre-

sence of which were accounted for by their being transported thither during submarine earthquakes.

An examination of the veins in the former case might indicate the presence of many other shells, and probably show the age of the veins of that district to be Liassic or Oditic. In the latter case, also, other remains might be found, and yield additional confirmation of the views I have propounded.

One reason for the non-discovery of organic remains has arisen from their being generally of small size, and that the vein-stuff in which they have to be sought for is often of a very intractable character, resisting the action of the water by which it has to be dissolved before they can be washed out of it, after which the residuum requires almost microscopic examination for their separation. In the process of washing away the "dowks," it is interesting to notice the very varied tints with which they colour the water, according to the mineralogical character of the material to be operated upon, which differs in separate districts, and on different levels or horizons in the same mine.

The organic remains thus obtained are occasionally even more varied, as regards genera and species, than if they had been derived from a given horizon of stratified deposits, arising perhaps from the length of time within which the fissure might have been open, and the necessarily mixed condition consequent upon the filling up of the vein. Some from the Carboniferous Limestone itself are associated with those which are foreign or derived. In the case of the Charterhouse Mine on the Mendips, those which are of Liassic age, and consequently derived, are in the proportion of about 90 to 30 from the older rocks within the walls of which they are found. In the Carboniferous-limestone districts of Holwell and Frome, Rhætic and Liassic organisms are also in large proportion; and the same may generally be said throughout the Mendip range and South Wales. In North Wales and the north of England, on the contrary, Carboniferous-limestone remains are the most frequent; those of later age are the exceptions, some of these being *Entomostraca* of Permian species, which may be common to the two series, and *Foraminifera*, which have a long range upwards. The precise later age of the vein-infillings is therefore, in their cases, not so clearly defined as in the south-west of England. In the Fallowfield Mine and the Silver Band Mines, *Pleurogites gracilis*, a seed of the coal-period, occurs, whilst at Grasington and Mold small particles of coal are occasionally present in the "dowks," which at Fallowfield and in the Swaledale district are so like material from the coal-shales that it is reasonable to infer that the veins are contemporary with, or subsequent to, the coal-period.

Nothing can well be more remarkable than the Mendip veins with their infillings of secondary age, high up on the Carboniferous-limestone tableland, and with no stratified deposits of lias within several miles. In the case of the Charterhouse Mine, from the variety in the contents of the fissures, there is ample evidence that a considerable time must have elapsed within which they remained more or less open, and during which various oceanic influences were at work. At 270 feet, the lowest depth of the shaft, there is found a deposit of blue or greenish clay, 10 feet in thickness, which has yielded the Liassic fossils given below. This, on the same level, occasionally changes from a homogeneous marl to patches of a more conglomeratic material with enclosed water-worn pebbles. Higher up the vein it becomes a dense conglomerate. Above this, sandy-looking deposits occur, which, when washed, are seen to be almost entirely composed of the detached stems of *enerinites* very much abraded, with small washed pebbles of

hæmatite iron-ore, showing that, after the deposit of the Lias in the vein below, a denudation of the Carboniferous Limestone had been going on; and above this, again, occurred calcspar and the largest deposits of lead-ore; all these changes, and others which might be mentioned, indicate the many conditions that were in operation before the fissure had finally received its contents, whilst still within the ocean's influence, and possibly before the final elevation of the Mendip range. In this district the minerals "prove" near the surface, but they are occasionally found below, and detached crystals of galena are not unfrequent in the Liassic clay at the bottom.

In the following list, which is extracted from my paper "On the Abnormal Condition of Secondary Deposits," &c., it will be seen what a large fauna occurs within the walls of the lead-vein, that most of the great palæontological groups are therein represented, and that they clearly indicate its precise geological age.

List of Organic Remains from Charterhouse Lead-mine, 270 feet from the Surface.

OF LIASSIC AGE.

Chara liassina, Moore.
 Drift-wood, Jet.
Cristellaria rotula, Lamk.
 ——— *costata, D'Orb.*
Dentalina communis, D'Orb.
 ——— *obliqua, Linn.*
 ——— *obliquestriata, Reuss.*
Fronclularia striatula, Reuss.
Involutina liassica, Jons.
 ———, sp.
Marginulina lituus, D'Orb.
Nodosaria raphaniistrum, Linn.
 ——— *radicula, Linn.*
 ——— *paucicostata, Reuss.*
Planularia Bronni, Roem.
Textularia, sp.
 Pentacrinites, joints of.
Cidaris Edwardsii.
 Echinodermata, several species.
 Ophioderma, joints of.
Serpula, sp.
Pollicipes rhomboidalis, Moore.
 Crustacea, claws of.
Bryozoa, sp.
Argiopo.
 Crania.
 Lingula.
Rhynchonella variabilis, Schloth.
Terebratula punctata, Sow.
 Spirifer, fragments, several sp.
Thecidium Moorei, Dav.
 ——— *triangularis, D'Orb.*
Zellania Davidsoni, Moore.
 ——— *Laboucherei, Moore.*
Lima, sp.
Plicatula spinosa, Sow.
Astarte, sp.
Cardinia multicosata.
Cucullæa.
Leda Heberti, Martin.

Nucula, sp.
Opis, sp.
Cerithium gratum, Terq.
 ——— *rotundatum.*
 ——— *pulchellum, Terq.*
 ——— *Semele, D'Orb.*
Chiton.
Fissurella.
Melania alternata, Terq.
Nerinea Mendipensis, Moore.
Orthostoma frumentum, Terq.
 ——— *triticeum, Terq.*
Pleurotomaria expansa, Sow.
 ——— *Mendipensis, Moore.*
Strophodontia tricarinata, Mart.
 ——— *Oppeli, Mart.*
Solarium lenticulare, Terq.
Trochus nitidus, Terq.
 ——— *edulus?, Stoll.*
 ———, sp.
Turbo, sp.
 ———, sp.
 ——— *Pictet, Martin.*
 ——— *aratus, Martin.*
 ——— *Martini, Terq.*
 ——— *tumidus, Moore.*
Turritella Humberti, Martin.
 ——— *Howsei, Moore.*
Ammonites, 2 sp.
Belonmites acutus, Mill.
 Fish remains abundant, including teeth
 of *Acrodus, Hybodus, Isipodus, &c.*,
 representing about ten species.
Ichthyosaurus, tooth of.

Derived from the CARBONIFEROUS
 LIMESTONE.

Helix Dawsonii, Moore.
Hydrobia, sp.
Planorbis Mendipensis, Moore.
Proserpina Lyalli, Moore.

Valvata anomala, Moore.

— *pygmaea*, Moore.

Vertigo Murchisoniae, Moore.

Bairdia plebeia, Reuss.

— *brevis*, Jones & Kirkby.

Cythere bilobata, Münster.

— *fabulina*, Jones & Kirkby.

— *intermedia*, Münster.

— *ambigua*, Jones, MS.

— *aqualis*, Jones, MS.

— *spinifera*, Jones, MS.

— *Thraso*, Jones, MS.

Kirkbya plicata, Jones & Kirkby.

Moorea tenuis, Jones, MS.

Terebratula hastata, Sow.

Orthis Michelini, Kon.

Atrypa, sp.

Spirorbis.

Serpula.

Encrinites.

Bryozoa, various species.

Corals, several species.

Echinodermata.

Conodonts.

Considerable palaeontological interest attaches to the presence, under these peculiar conditions, of such genera as *Helic*, *Prosopina*, and *Vertigo*, as, with one exception, they are the earliest recognized land shells, and also to *Valvata*, *Hydrobia*, and *Planorbis*, the oldest freshwater genera yet known. In the paper above mentioned, I referred to the difficulty that exists in always assigning the shells of different ages, when thus mixed together, to their true geological horizons. Although in general this difficulty does not occur, it may happen with those which are new, or have not been previously stratigraphically recognized.

It was not unnatural that I should have supposed these land and freshwater shells, when accompanied by a large Liassic fauna, to be of the same age; but with regard to the *Valvata anomala*, the *V. pygmaea*, and the *Planorbis Mendipensis*, the evidence I have since obtained of the presence of these shells in the mining-districts of the North, leads me to the conclusion that it is probable that these land and freshwater species are rather to be assigned to the earlier period of the Carboniferous Limestone, a fact that will still enhance their palaeontological interest. The presence also of other freshwater genera, to be hereafter noticed, occurring in considerable numbers in the veins, induces me to think that there are some freshwater beds connected with the Carboniferous Limestone from whence they may have been derived which have yet to be discovered; and I hope my geological friends who are working in Carboniferous-limestone districts will turn their attention to this point; for of all formations, less, I believe, is really known or realized of the great physical, palaeontological, and other changes which have occurred during the Carboniferous period than of most other geological deposits, and there yet remains a great work for some geologists to take up in this direction.

In other mining-districts organic remains are generally less plentiful than in the Mendip area; but I have not failed to detect them, more or less abundantly, except in one instance, in that of the Cononley Mine in the Airdale district. It often happens that, though they are wanting in some samples of the "dowks," they may still be obtained from others at higher or lower levels in the same mine. Although they have in all instances been selected promiscuously for examination, fossils have been found in more than one half of the samples.

The following lists of "dowks," with notes of their organic contents, are selected to show the general character of the vein-stuff after it has been prepared by washing.

Keld-Head Mines, Wensleydale.

48 ft. from surface. A very mineralized, brownish, or drab marl; when washed chiefly a residuum of quartz grains. Organisms rare, consisting of *Encrinites*, *Serpula*-like tubes, *Involutina*.

- 90 ft. Dowkey Vein, Ashbank Limestone, with occasional galena and iron pyrites. *Enerinites* very abundant. *Serpula*, *Orthis*, *Involutina*, rare.
- 192 ft. Keld-Head Vein, Ashbank Limestone, a drab marl, leaving a very quartzose residuum, with iron pyrites. *Enerinites* abundant; *Involutina* rare.
- 210 ft. Cobsear Vein, Undersill Limestone, a brownish marl, with yellow sandy patches. *Valvata anomala* (Moore), *Entomostraca*, *Echini*, *Bryozoa*, *Seed*?, *Enerinites*, abundant, *Brachiopoda*.
- 240 ft. West-Bank Vein, Ashbank Limestone, a greyish marl, with numerous *Foraminifera* of the genera *Involutina*, *Entomostraca*, many *Enerinites*, *Serpula*, *Bryozoa*, &c.
- 450 ft. Keld-Head Vein, Bottom Limestone, a blue marl, with galena, blende, iron pyrites, quartz, selenite. *Planorbis Mendipensis* (Moore) and other univalves; *Euomphalus*, *Entomostraca*, many *Enerinites*, *Echini*, *Serpula*, *Bryozoa*, *Discina nitida*, *Terebratula*, very numerous; *Involutina*, *Dentalina pauperata*, very rare.

Aysgarth Top Limestone, a dark-blue mineralized residuum with galena, blende, iron pyrites. *Entomostraca*, numerous *Foraminifera*.

Thornton's Scar Limestone, a blue marl. Casts of bivalves, *Enerinites* abundant, and many *Foraminifera*.

List of Fossils in Keld-Head Mines.

Seed?	Lingula, sp.
Involutina silicea, <i>Terquem</i> .	Productus, sp.
— polymorpha, <i>Terq.</i>	Rhynchonella, sp.
— liassica, <i>Jones</i> , sp.	Terebratula hastata, <i>Sav.</i>
— radiata, <i>Brady</i> .	Zellania, ? sp.
— lobata, <i>Brady</i> .	Bivalves, fragments, sp.
Dentalina pauperata, <i>D'Orb.</i>	Hydrobia, n. sp.
Bairdia curta, <i>McCoy</i> .	Stoastoma ?, n. sp.
— plebeia, <i>Reuss</i> , long var.	Valvata pygmaea, <i>Moore</i> .
—, sp.	— anomala, <i>Moore</i> .
Cythere cuneolina, <i>J. & K.</i> , MS.	Planorbis Mendipensis, <i>Moore</i> .
— fabulina, <i>J. & K.</i> , MS.	Loxonema brevis, <i>McCoy</i> .
—, n. sp.	Lacuna antiqua, <i>McCoy</i> .
Corals, sp.	Macrochellus trilineatus, <i>McCoy</i> .
Enerinites.	Murchisonia quadricarinata, <i>McCoy</i> .
Echini, sp.	— Laurembi, <i>McCoy</i> .
—, sp.	— trilineata, <i>McCoy</i> .
Serpula, sp.	—, sp.
Spirorbis caperatus, <i>McCoy</i> .	—, sp.
Bryozoa, several sp.	—, sp.
Atrypa, sp.	Pleurotomaria multicaarinata, <i>McCoy</i> .
Discina nitida, <i>Phil.</i>	— sulcata, <i>Phil.</i>
Chonetes, sp.	— limbata, <i>Phil.</i>
Orthis, sp.	

Fallowfield and Brownley Hill, Cumberland.

- 90 feet from surface. Fallowfield Vein, a very micaceous grey marly residuum, with black carbonaceous particles, fragments of coal, crystals of selenite, iron pyrites. *Flemingites gracilis* (Varr.), porcelain-like casts of *Turbo* and *Turritella*, *Entomostraca*, *Foraminifera*.
- 270 ft. Fallowfield Vein, a dark marl, with iron pyrites. *Turbo*, *Turritella*, *Entomostraca*, *Enerinites*.
- 450 ft. Brownley Hill Old Vein, a black micaceous marl, with selenite. *Stro-*

stoma? in considerable numbers; *Hydrobia*, n. sp., *Pisidium*, *Unio?*, *Spirifer*, *Dentalina*, *Serpulæ*, *Entomostraca*, *Bryozoa*.

480 ft. Brownley Hill Middle Vein, a black micaceous marl. No organisms.

600 ft. Brownley Hill West High Cross Vein, a dark mineralized micaceous slaty deposit, with encrinite-stems rarely.

80 ft. Guddingill Burn Cross Vein, a black slaty marl, like Coal-measure shales. Encrinite-stems, remains rare.

Fossils in Fallowfield and Brownley Hill Veins. Brownley Hill 1400 feet, Fallowfield 100 feet above Sea-level.

Flemingites gracilis, Carr.	Unio?, n. sp.
Involutina.	Bivalves, sp.
Dentalina pauperata, D'Orb.	Spirifer, sp.
Echini, sp.	Stenostoma?, n. sp.
Serpulæ.	Hydrobia, n. sp.
Serpulites, sp.	Valvata anomala, Moore.
Bryozoa, sp.	Dentalium inornatum, M' Coy.
Encrinites.	Turbo, sp.
Cythere fabulina, J. & K., n. sp.	Turritella, sp.
— cuneolina, J. & K., n. sp.	Conodonts.
—, n. sp.	—
Pisidium, n. sp.	Coal.

Grassington Mines, Wharfedale, Yorkshire.

24-fathoms level. New Bake Vein, residuum a yellow sandy ferruginous marl, with hematite iron-ore, quartz, &c., fragments of coal and coal-like shale. Encrinital stems.

28-ft. level from the shale, a brown and red-mottled marl, with a very mineralized residuum, manganese, iron-ore, quartz, &c. Tooth of *Petalodus*, *Conodonts*, *Echini*, *Serpulæ*.

60-ft. level, near the junction of Eddey's and Cannister's Veins, a yellow marl, residuum almost entirely composed of encrinital stems.

60 ft. on Eddey's Vein, a brown marl, with manganese, iron-ore, quartz, fish-teeth and scales, *Conodonts*, *Encrinites*, *Serpulæ*.

60 ft. on Middle Vein, a greyish marl, in great part encrinital. Small fish-palate and other fish-remains, *Conodonts*.

60 ft. at Moss Middle Vein, a yellowish marl, leaving a variegated irony residuum. Teeth of *Petalodus* and *Orodus*, and fish-scales, *Conodonts* of two forms, *Serpulæ*, *Encrinites*, *Involutina*.

60 ft. Old Moss Vein at Moss, a yellowish sandy marl. Scales or teeth of *Ctenopterygius*; organisms rare.

40 ft. Middle Vein, Coalgrove Head, a drab marl, chiefly encrinital. Tooth of *Orodus*, small vertebra and fish fragments, vegetable-like fragments, *Conodonts*, *Bryozoa*, *Involutina*.

40 ft. Old Ralph's String Level, Coalgrove Head, a grey mottled marl. Fish-teeth, *Conodonts*, *Encrinites*, *Scal?*, *Involutina*.

18 ft. Cavendish Vein, at Sarah Top, Millstone-grit, a cream-coloured marl, with galena. No organisms.

37 ft. Cavendish Vein, Sarah Top, part of Millstone-grit, a brownish-looking sample, conglomeratic, with limy streaks in the laminae. Hematite iron-ore, micaceous sandstone, lignite or coal, quartz, galena, leaving a large limy deposit in the water. Encrinital stems.

- 42 ft. No. 2 Vein, north of Middle Vein, Friendship, a brownish marl, with *Planorbis*, *Bryozoa*, *Serpula*, *Encrinites*.
- 42 ft. No. 4 Vein, south of Middle Vein, at Friendship, an ochreous marl, with *Hydrobia*, *Entomostraca*, *Conodonts*, *Serpula*, *Encrinites*, *Involuntina*, *Nodosaria*.
- 45 ft. Alexander Vein, West Peru. *Hydrobia*, *Conodonts*, &c.
- 40 ft. Alexander Vein, West Peru, a brownish marl, with fish-remains, *Conodonts*, *Entomostraca*, *Rhynchonella*, &c.
- 45 ft. New Vein, West Peru, a brownish-mottled marl, with part of fish-jaw, teeth of *Petalodus* and *Orodus*, fish-vertebrae and scales. *Hydrobia*, *Discina nitida*, *Lingula*, *Conodonts*, *Dentalium inornatum*, *Encrinites*, *Bryozoa*, *Echini*. Crustacean fragments?
- 24 ft. No. 2 Vein, south of West Turfit's shaft, a grey clay, with *Psummodus* tooth, *Univalves*, *Bryozoa*, *Encrinites*, *Coral*, *Involuntina*.
- 25 ft. On Ringleton's Vein, a brownish-mottled marl. Tooth of *Orodus*, *Hydrobia*, *Valvata anomala*, *Crania?*, *Conodonts*, *Entomostraca*, *Bryozoa*, *Dentalium*, *Serpula*, *Encrinites*, *Involuntina*.
- 20 ft. New Rake Vein, a brownish-mottled marl. Piece of large tooth, fish-spinos, and small teeth, *Valvata anomala*, *Hydrobia*, *Lithoglyphus*, *Planorbis*, *Conodonts*, *Entomostraca*, *Bellerophon*, *Encrinites*, &c.
- 24 ft. Branch, north from New Rake Vein, in shales and limestone, an irony-looking marl. *Encrinital* stem.

List of Fossils in the Grassington Mines, 1300 feet above Sea-level.

Vegetable-like fragments.

Seeds?

Involuntina vermiformis, *Brady*.

— *aspera*, *Brady*.

— *recta*, *Brady*.

— *incuta*, *Brady*.

— *nodosa*, *Brady*.

— *cylindrica?*, *Brady*.

— *polymorpha*, *Terg.*

Nodosaria, sp.?

— *radicula*, *Linn.*?

Corals, sp.

Encrinites.

Echini, remains.

Serpula.

Serpulites, sp.

Cythere nigrescens.

— *nunda*.

— *aqualis*, sp. n.

— *bilobata*, *Münst.*

— *intermedia*, *Münst.*

— *Münsteriana*, *J. & K.*

— *ambigua*, *J. & K.*, MS.

— n. sp.

Leperditia Okeni, *Münst.*

Crustacean fragment.

Conodonts.

Bryozoa, sp.

Discina nitida, *Phil.*

Lingula, sp.

Rhynchonella, sp.

Leptæna, sp.

Thecidium?, sp.

Zellania?, sp.

Terebratula hastata, *Phil.*

Bivalves, fragments.

Hydrobia, n. sp.

Lithoglyphus, sp.

Planorbis Mendipensis, *Moore*.

Valvata anomala, *Moore*.

Dentalium inornatum, *M'Coy*.

Turbo, sp.

Cladodus, tooth.

Psummodus, tooth.

Petalodus, tooth.

Orodus, tooth.

Part of fish-jaw.

Vertebro and fish-scales.

Conchoidal-like shale.

Various minerals.

List of Fossils from the Alston Mines, 1240 feet above Sea-level.

Carteria, sp., nov. gen.

Encrinites.

Echini.

Serpula.

Serpulites.

Corals, sp.

Cythere pyrula, *J. & K.*, n. sp. MS.

— *nigrescens*.

Cythere Moorei, *Jones*.
 Leperditia Okeni, *Münst.*
 ——— parallelata, *J. & K.*
 Arca, sp.
 Nucula, sp.
 Bryozoa, sp.
 Terebratula hastata, *Sow.*
 Spirifera.
 Buccinum imbricatum, *Sow.*
 Cirrus Dionysii, *Goldf.*
 Hydrobia, n. sp.

Dentalium inornatum, *M'Coy*.
 Natica.
 Macrocheilus curvilineus, *Phil.*
 ——— canaliculatus, *M'Coy*.
 Murchisonia Larcumbi, *M'Coy*.
 Pleurotomaria sulcata, *Phil.*
 ——— interstitialis, *Phil.*
 Turbo, sp.
 Univalves, several sp.
 Petalodus, tooth. ———

List of Fossils from Weardale Mines.

Carteria, sp., nov. gen.
 Corals.
 Encrinites.
 Echini.
 Spirorbis caperatus, *M'Coy*.
 Serpula.
 Leperditia Okeni, *Münst.*
 Cythere, sp.
 Atrypa, sp.
 Orthis, sp.
 Spirifera Uriei, *Flem.*
 Arca, sp.

Nucula, sp.
 Bellerophon globatus?
 Elenchus antiquus, *M'Coy*.
 Loxonema brevis, *M'Coy*.
 Murchisonia quadricarinata, *M'Coy*.
 Turbo, sp.
 Univalves, several other sp.
 Conodonts. ———
 Vegetable-like impressions.
 Sponge-like bodies.

List of Fossils from Allenhead Mines.

Plantæ.
 Sponge-like bodies.
 Corals, sp.
 Encrinites, sp.
 Echini, sp.
 Serpula.
 Serpulites.
 Leperditia Okeni, *Münst.*
 Cythere pyrula, n. sp.
 ——— Geinitzianna, *Jones*.
 ——— nigrescens.
 ——— Moorei, n. sp.
 ——— subulina, *J. & K.*
 Bairdia plebeia, *Reuss*.
 ——— elongata, *Münst.*
 Atrypa, sp.
 Chonetes, sp.
 Terebratula hastata, *Phil.*

Productus, sp.
 Spirifera, sp.
 Bivalves, portions.
 Arca, sp.
 Psammodus, tooth.
 Hydrobia, n. sp.
 Valvata anomala, *Moore*.
 Elenchus antiquus, *M'Coy*.
 Loxonema brevis, *M'Coy*.
 Murchisonia quadricarinata, *M'Coy*.
 Natica.
 Bellerophon.
 Conodonts. ———
 Coal-like fragments.

List of Fossils from the White and Silver Band Mines.

Flemingites gracilis, *Carr*.
 Seed?
 Spongiform bodies.
 Encrinites, sp.
 Serpula, sp.
 Serpulites, sp.
 Corals, sp.
 Echini, sp.
 Involutina silicea, *Terg.*
 ——— liassica, *Jones*.

Dentalina pauperata, *D'Orb.*
 Bryozoa, sp.
 Bivalves, in pieces.
 Enomphalus?
 Stenostoma?, sp.
 Hydrobia, sp.
 Valvata anomala, *Moore*.
 Psammodus, tooth.
 Conodonts, two kinds.

List of Fossils from Mount Pleasant Mine, Mold, Flintshire, about 1000 feet above Sea-level.

Seeds ?	<i>Orodus cinctus</i> , <i>Ag.</i>
Encrinites.	<i>Psummodus</i> , teeth.
Serpulae.	<i>Petalodus</i> , teeth.
Involuntina.	Saurichthys-like teeth.
Dentalina ?	<i>Cladodus</i> , teeth.
<i>Cythere Wardiana</i> , <i>J. & K.</i> , n. sp.	Squaloraria-like scales.
Chiton-like valves.	Tooth, with serrated edges.
Bivalves, in fragments.	Reptilian-like tooth.
<i>Terebratula</i> , sp.	Scales, lozenge-shaped, of fishes.
Spirifer, sp.	Conodonts.
Hydrobia, sp.	
<i>Euomphalus</i> , sp.	White siliceous fragments of stone, with numerous scattered fish-remains.
<i>Otenoptychius</i> , tooth or scale.	

List of Fossils from the Coldberry and Red Grove Mines, Tredate.

Seed ?	<i>Nucula</i> , sp.
Encrinites.	Impressions of bivalves in vein-stuff.
Echini.	<i>Terebratula hastata</i> , <i>Phil.</i>
Serpulites.	<i>Bellerophon</i> , sp.
Involuntina.	<i>Dentalium inornatum</i> , <i>M'Coy.</i>
<i>Cythere bilobata</i> , <i>Münst.</i>	<i>Hydrobia</i> , n. sp.
— <i>pyrula</i> , <i>J. & K.</i> , MS.	<i>Planorbis Mendipensis</i> , <i>Moore.</i>
<i>Cytherella aspera</i> , <i>Jones</i> , n. sp.	<i>Valvata anomala</i> , <i>Moore.</i>
Corals.	<i>Psummodus</i> , tooth.
Area, sp.	Spine-like bodies.

List of Fossils from a Vein at Weston-super-Mare.

Encrinites.	<i>Kirkbya impressa</i> , n. sp.
<i>Leperditia Okeni</i> , <i>Münst.</i>	<i>Bairdia plebeia</i> , <i>Reuss.</i>
<i>Cythere pyrula</i> , n. sp.	<i>Glaucanome grandis</i> , <i>M'Coy.</i>
— <i>nigrescens</i> .	<i>Buccinum imbricatum</i> , <i>Phil.</i>
— <i>fabulina</i> , <i>J. & K.</i>	<i>Melania</i> , sp.
— <i>Moorei</i> , n. sp.	<i>Natica variata</i> , <i>Phil.</i>
<i>Beyrichia arcuata</i> .	<i>Hydrobia</i> , n. sp.
— <i>subarcuata</i> .	Univalves, several sp.
— ? <i>impressa</i> , n. sp.	Fish-scales.
<i>Kirkbya plicata</i> , n. sp.	
— <i>costata</i> , <i>M'Coy.</i>	Galena and copper-ore.

Whilst the various mines and mineral deposits I have examined have certain species in common, it may be said that they have each special paleontological features of their own.

In the Keld-Head Mines organic remains are very abundant at about 450 feet from the surface, amongst which are many Foraminifera, chiefly of the genus *Involuntina*, of which there are six species, and univalves of about twelve genera, the freshwater genera *Valvata anomala*, Moore, and *Planorbis Mendipensis*, Moore, being present, and also Entomostraca of several new species.

The Fallowfield mines, although not yielding a very long list of species, have their special interest in the presence of the land and freshwater genera *Stoastoma*?, *Hydrobia*, and *Psidium*; *Involuntina*, as in the Keld-Head mines, though rarely; and a single seed of the *Flemingites gracilis*, Carr. The richest samples from this mine are at 90 and 450 feet from the surface.

The Grassington mines are not only very rich in individual specimens, but have yielded the greatest number of species, amongst which are again

freshwater remains of *Hydroidia*, *Planorbis*, *Valvata*, and *Lithoglyphus*, Entomostraca of at least ten species, Conodonts of several varieties, and fish-remains of the genera *Petalodus*, *Orodus*, &c.

The Alston mines have yielded about twelve species of univalves, though they are not in good condition; Foraminifera are present, but are rare, and fish-remains of the genera *Petalodus*.

The Weardale mines, and those of Allenheads, are comparatively not rich, the vein-stuff in them being much mineralized. Conodonts occur in the former, Entomostraca rather abundantly in the latter, and also, though rarely, the genus *Hydroidia*. In these veins, and also at Alston, I have detected, for the first time, large cells of a foraminiferous shell, for which Mr. Brady suggests the generic name *Carcharia*.

In the White and Silver Band mines remains are somewhat rarely distributed, the richest deposit being a friable ochreous sandstone, on the "sun" side of the Silver Band Old Mine, which yielded many specimens of *Hydroidia*, and one or two of *Valvata anomala*, several genera of Foraminifera, including *Involutina* and *Dentalina*, with Conodonts and portions of teeth of *Parnacodus*.

The Mount-Pleasant mines of Mold contain Foraminifera, and also the freshwater *Hydroidia*, though rarely, and Conodonts rather abundantly; but they are especially remarkable for the great variety of fish-remains they yield, which appear to represent at least ten different genera. Mixed with the "dowls" of the mine are occasionally small pieces of laminated stone, the surfaces of which exhibit numerous traces of fish-scales.

The researches I have been making have involved very considerable labour and minute investigation; but as they will to some extent have opened up a new field of inquiry, I hope they will not be without some results. Before concluding, I desire to refer to several of the more interesting paleontological facts which have been obtained.

Flemingites gracilis, Carr.—These are the almost microscopic sporangia or seeds of a coniferous tree of the Carboniferous period, which have been described and figured by my friend Mr. Carruthers in the 'Geological Magazine,' vol. ii. p. 443, my first acquaintance with which was by finding a single specimen in the Fallowfield Mine, followed soon after by another from the Silver-Band mines. It is remarkable, when a key is once obtained to the discovery of certain organic remains, how soon our knowledge of the class may be increased. In the instance of these minute seeds, I have since found them abundantly in the Carboniferous series of Staffordshire, and within the last few weeks more abundantly still in the Coal-measures of Radstock, Somersetshire. At this place there is a horizontal bed of some thickness, intercalated with the coal-seams, which appears to be almost wholly composed of these little organisms; and, extraordinary as it may seem, it is not far from the truth when I say that I could supply specimens of them by the ton weight!

Conodonts.—In many of the lists of fossils I have given, the presence of these curious organisms may be seen. Hitherto they have not been found by any one but myself above Lower Silurian rocks, though no doubt they may henceforth be detected in the strata of great thickness intervening between the Ludlow bone-bed and the Carboniferous period from whence my specimens come. I have not only found them in the lead-veins, but also in stratified beds of Carboniferous Limestone at Almondsbury near Bristol.

The series of these remarkable microscopic bodies I have discovered yield much greater variety than any hitherto obtained, and consequently present

additional difficulty in determining their affinities. They are generally either lustrous or horny in their appearance, or dull, according to the matrix in which they are found. My collection of them affords certain well-marked recurrent types, which enable a certain amount of classification to be given to them; and though, taking the group as a whole, their forms are about as eccentric as can be imagined, they still do not appear to pass one into another. The simplest form is almost identical in shape with that of a minute conical fish-tooth. Next comes another, not unlike the central cusp of a hyoid tooth, with lateral bosses at the base. Another group possesses an arched base, the simplest form in which has an elevated central curved tooth, with a smaller projecting tooth on either side. A second form has four elevated slightly curved teeth, with smaller teeth at the sides and in the interspaces, whilst a still more elaborate one possesses a single elevated central curved tooth, with about twelve regularly arranged, close-set smaller ones on either side. A third group have their teeth arranged on an irregular or wavy base, the forms of which are almost too eccentric for description. In one there are nine curved teeth, arranged somewhat symmetrically, graduating in height to the centre, but with a much larger fang at one end; a second form has five tapering teeth, followed by four others, much more depressed and extended beyond the base. One kind presents a miniature representation of the jaw of *Rhizodus*, with large teeth widely separated, and irregularly dispersed small teeth within. A remarkable form possesses a long curved tooth at one end, throwing off a semicircular spur, which passes under a base-line, on the top of which follow numerous small depressed regular teeth, the next two becoming much elevated, whilst the last is still more so, extending much beyond the basal end. Another series, which has a lengthened straighter base-line, is furnished in some instances with serrations as close-set and minute as are the bristles on an insect's limbs. In the width, form, and curvature of the teeth, these present various modifications. Although in the above short descriptions I have by no means exhausted the variety they present, I shall only notice here another kind, which is the most abundant, and similar to one previously found in the Ludlow bone-bed. This presents a somewhat club-shaped form, the thicker end having in the centre a depression, bounded on the margin by a raised edge, furnished with very minute serrations, which are united at about the centre of the body, and are continued beyond in a very thin slightly curved handle, which is also furnished with close comb-like teeth. A familiar illustration of this Conodont would be that of an old-fashioned rat-trap. Its base possesses a somewhat triangular hollow, indicating that it might have been attached at this part to some soft body.

These curious fossils were first found by Pander, in Silurian beds in Russia; and considering that they belonged to and were the teeth of fish, he created 13 genera and 56 species, according to the forms they presented. In almost every instance the specimens I have found differ from those of the Silurian beds, and present much more diversity. Several of the Russian varieties were, for the first time, noticed in the Ludlow bone-bed by Dr. Huxley, who, in a paper in the 'Geological Journal,' 1861, p. 549, suggests that they may be minute spines attached to the tail of a crustacean, such as *Ceratoparis*.

They have more recently been noticed by Professor Owen, in a note to the last edition of 'Siluria,' p. 544, in which he also points out the improbability of their being allied to fish. He then remarks that certain parts of small crustacea, such as the pygidium or tail of minute Entomostraca, resemble

in shape the more simple Conodonts; but that against this view was the fact that no shells of Entomostraca or other crustaceans had ever been found in the Conodont beds, and that it was improbable therefore that they could have belonged to an organism as susceptible of preservation as their own substance. Although I may agree with the opinion of Professor Owen, that these bodies do not belong to Entomostraca, I do so for other reasons. In the first place, although his remarks may apply to the Silurian Conodonts, he is wrong in supposing that they do not occur in the same beds with Entomostraca; for it happens that most of my specimens from the Carboniferous Limestone are found in beds crowded with Entomostraca, which occur also in the lead-veins, these two sources having yielded me about 40 species. The great variety my series of Conodonts presents is decidedly against referring them to Entomostraca; and what is, I think, sufficiently conclusive is the fact that they are usually of greater size than the crustaceans, to which they would thus be attached. The conclusion to which he arrives respecting them is, that they were united to a soft perishable body, and that they have most analogy with the spines, hooklets, or denticles of naked Mollusks and Annelides. There is no doubt great difficulty attending their elucidation, and the above view, though not, I think, quite satisfactory, appears as probable as any other that has been advanced. One objection to it is the variety of forms they present, and that we have no existing analogues. To whatever they belonged, the creatures yielding them probably passed away with Palæozoic times, as I have found no trace of them in my examinations of any later deposits. It has always been my object, when seeking them in the Carboniferous Limestone, to find their association with some other organized body, but in this I have always failed. They invariably occur as separate detached specimens, and without any arrangement as regards one another.

Entomostraca.—The bivalve crustacea included in this family, although not individually numerous, are present in nearly every vein I have examined. They have been in the hands of my friend Professor Rupert Jones, who has provisionally determined about 29 species from the veins, including those of Charterhouse and Weston, the great majority of which are new. They include the genera *Bairdia*, *Beyrichia*, *Cythere*, *Cytherella*, *Kirkia*, and *Moorea*, the genus *Cythere* alone having as many as seventeen species.

Foraminifera.—Our knowledge of some of this very beautiful class of microzoa will be considerably extended by those I have been fortunate enough to obtain from the lead-vein deposits. This will especially apply to the genus *Involutina*, which until lately was chiefly known by a single species of *I. liassica*, Jones, sp., many specimens of which I have found in the Liassic deposit in Charterhouse Mine. More recently M. Terquem's researches in the Lias of the north-west of France have brought to light several new forms belonging to the same type, four of which, viz. *I. polymorpha*, *I. aspera*, *I. silicea*, and *I. nodosa*, all supposed to belong to the secondary age, are represented in my gatherings from the Carboniferous Limestone veins. My series not only carries back the above secondary species to deposits of Palæozoic times, but associated with them are nine others, so that under these peculiar conditions there are not less than fourteen species of this hitherto little-known genus. *Dentalina pauperata*, D'Orb, a now living species, which has been traced back through Tertiary, Liassic, and Permian formations, not only in this series goes back to the Carboniferous Limestone, but I have also obtained it in the Wenlock shales, an evidence of a delicate microscopic shell having existed through a long series of ages to our
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own times. The *Tinaporus levis*, P. & J., another recent species, will probably be added to the list, though it requires more examination, together with the recent species *Textularia sagittula*, DeFrance, and the genus *Fusulina*. The cells of the new genus *Carteria* have since been found somewhat abundantly on the decomposed edges of the Carboniferous-limestone rock of Mfihills. Thus there are twenty-one species of Carboniferous-limestone Foraminifera unexpectedly making their appearance for the first time in mineral veins, three of which have lived on to this day.

Land and Freshwater Shells.—Not the least important fact in my mine explorations has been the discovery of a land and freshwater fauna. Until I obtained the three genera of *Helix*, *Vertigo*, and *Proserpina*, with the freshwater genera *Planorbis* and *Valvata*, in the Charterhouse Mine, the only known terrestrial shell below the secondary beds was the *Pupa vetusta*, Daw., found by Sir Charles Lyell and Dr. Dawson in the Coal-measures of Nova Scotia. To the above genera I have now to add those of *Hydrobia*, *Stoastoma*?, *Lithoglyphus*, and *Pisidium*, from the mines of the north of England, some of which I have little doubt are older than the *Pupa vetusta* of the coal-beds. There is thus the fact of the presence of nine genera of land and freshwater shells in the lead-veins of this country.

In addition to the list of organic remains which follows, numbering about 112 species from the north of England and North-Wales mines, eight, which are not in common, have been obtained from Weston, and to these again are to be added 89 in the list previously given from Charterhouse, so that in true and workable mineral veins I have found 209 species. In the Carboniferous Limestone of the Frome district precisely similar phenomena occur, though the fissures are not worked. These Rhætic and Liassic veins have yielded me about 70 species, so that, including the districts I have enumerated, I have obtained from vein-fissures, with their deposits of different ages, about 279 species of organic remains.

Under these peculiar circumstances, I have discovered the oldest known Mammalia, the oldest land and freshwater Mollusca, about 52 species of fish, and about 8 of Reptilia, besides the other groups to which reference has been made.

The list of species from Charterhouse Mine previously given and those from Weston are not included in the following list. The species of Foraminifera marked "*Brady*" are new to science, and descriptions of them will be found in Mr. H. B. Brady's "Notes on the Foraminifera" immediately following this Report, as well as a provisional notice of the new genus *Carteria*.

List of Species.	Mines.						
	Grassington.	Fallowfield &c.	White and Silver Band.	Teesdale.	Allenheads.	Alston.	Keld Heads.
Flemingites gracilis, Carr.	..	..	..	..	..	..	..
Seeds ..	..	..	..	..	..	..	..
Plants, impressions on shale ..	..	..	..	..	..	..	..
Sponge-like bodies ..	..	..	..	..	..	..	..

TABLE (continued).

List of Species.	Mines.							
	Crassington.	Fallowfield &c.	White and Silverband.	Teesdale.	All-n-heads.	Alston.	Keld Heads.	Mount Pleasant.
<i>Nodosaria radiclea</i> , Linn. ?	*							
—, sp. ?	*							
<i>Textularia sagittula</i> , DeFrance.								
<i>Tinoporus</i> , sp. ?				*				
<i>Dentalina pauperata</i> , D'Orb.		*	*				*	
<i>Fusulina</i> ?, young								
<i>Involutina polymorpha</i> , Terquem.	*							*
— <i>aspera</i> , Terq.	*							
— <i>silicea</i> , Terq.	*		*				*	
— <i>nodosa</i> , Terq.	*		*				*	
— <i>Linssica</i> , Jones, sp.							*	
— <i>radiata</i> , Brady							*	
— <i>subrotunda</i> , Brady				*			*	
— <i>lobata</i> , Brady				*			*	
— <i>crassa</i>								
— <i>vermiformis</i> , Brady	*							
— <i>incerta</i> , Brady	*							
— <i>recta</i> , Brady	*							
— <i>cylindrica</i> , Brady	*							
— <i>obliqua</i> , Brady	*							
<i>Carteria</i> , sp., nov. gen.					*	*		
<i>Corals</i> , sp.	*			*	*	*		
<i>Enerinites</i> , sp.	*			*	*	*	*	
<i>Echinodermata</i> , sp.	*	*	*	*	*	*	*	*
— sp.	*			*	*	*	*	*
<i>Serpula</i>	*			*	*	*	*	
<i>Serpulites</i>	*	*	*	*	*	*	*	*
<i>Spirorbis caperatus</i> , M' Coy	*			*	*	*	*	*
<i>Crustacea</i> , fragment	*				*	*	*	
<i>Bairdia plebeia</i> , Reuss	*				*	*	*	
— <i>curta</i> , M' Coy					*	*	*	
— <i>elongata</i> , Münster.					*	*	*	
— sp.					*	*	*	
<i>Beyrichia</i>	*						*	
<i>Cythere bilobata</i>	*			*				
— <i>pyrula</i> , n. sp.				*	*	*		
— <i>nigrescens</i>	*				*	*		
— <i>munda</i> , n. sp.	*					*		
— <i>sequalis</i> , n. sp.	*							
— <i>intermedia</i> , Münster.	*							
— <i>fabulina</i> , J. & K.	*	*			*		*	
— <i>ambigua</i> , Jones, n. sp.	*				*			
— <i>Moorei</i> , Jones, n. sp.						*		
— <i>cuncolina</i> , J. & K., n. sp.		*			*		*	
— <i>Muensteriana</i> , J. & K.	*							
— <i>Wardiana</i> , J. & K., n. sp.								*
—, n. sp.	*				*		*	
—, <i>Geinitziana</i> , Jones					*			
<i>Cytherella aspera</i> , Jones, n. sp.				*				
<i>Leperditia Okeni</i> , Münster.					*	*		
— <i>parallela</i> , J. & K.					*	*		
<i>Bryozoa</i> , various sp.	*	*	*		*	*	*	
<i>Atrypa</i> , young					*	*	*	
<i>Chonetes</i> , sp.					*	*	*	

TABLE (continued).

List of Species.	Mines.						
	Grass- ton.	Fallow- field &c.	White and Silver Band.	Tree-dale.	All-nheads.	Al-ton.	Keld Hads. Mount Pleasant.
<i>Diacina nitida</i> , Phil.	•	•					•
<i>Leptena</i> , sp.	•	•					
<i>Lingula</i> , sp.	•	•					•
<i>Productus</i> , sp.	•	•					
<i>Orthis</i> , sp.	•	•			•		
<i>Rhynchonella</i> , sp.	•	•					
<i>Spirifera</i> , sp.	•	•					•
<i>Thecidium</i> ?	•	•					
<i>Zellania</i> ?	•	•					
<i>Terebratula hastata</i> , Phil.	•	•		•	•		
<i>Brachiopoda</i> , sp.	•	•					
Bivalves, fragments	•	•	•				•
<i>Arca</i> , sp.	•	•					
<i>Nucula</i> , sp.	•	•					
<i>Pisidium</i> , sp.	•	•					
<i>Stoastoma</i> ?, sp.	•	•	•				
<i>Hydrobia</i>	•	•	•	•	•		•
<i>Lithoglyphus</i>	•	•					
<i>Planorbis Mendipensis</i> , Moore	•	•					
<i>Valvata anomala</i> , Moore	•	•	•		•		•
— <i>pygmaea</i> , Moore	•	•					
<i>Buccinum imbricatum</i> , Sonc.	•	•					
<i>Cirrus Dionysii</i> , Goldf.	•	•					
<i>Dentalium inornatum</i> , M ^c Coy	•	•					
<i>Elenchus ambiguus</i> , M ^c Coy	•	•			•		
<i>Lacuna antiqua</i> , M ^c Coy	•	•					
<i>Loxonema brevis</i> , M ^c Coy	•	•					
<i>Murchisonia Lecombi</i> , M ^c Coy	•	•					
— <i>quadricarinata</i> , M ^c Coy	•	•					
<i>Macrocheilus curvilineus</i> , Phil.	•	•					
— <i>canaliculatus</i> , M ^c Coy	•	•					
— <i>tricinctus</i> , M ^c Coy	•	•					
<i>Natica</i>	•	•					
<i>Pleurotomaria sulcata</i> , Phil.	•	•					
— <i>interstitialis</i> , Phil.	•	•					
— <i>multicarinata</i> , M ^c Coy	•	•					
— <i>limbata</i> , M ^c Coy	•	•					
<i>Turritella</i> , sp.	•	•					
<i>Turbo</i> , sp.	•	•					
<i>Bellerophon</i> , sp., young	•	•					
<i>Euomphalus</i> , sp.	•	•					
<i>Goniatites</i> , sp.	•	•					
<i>Cladodus</i> , teeth	•	•					
<i>Otmoptychius</i> , tooth	•	•					
<i>Orodus</i> , teeth	•	•					
<i>Petalodus</i> , teeth	•	•					
<i>Psemmodus</i> , teeth	•	•					
<i>Saurichthys</i> , tooth	•	•					
Squid-like scales	•	•					
Jaw of Fish, portions	•	•					
Fish-scales	•	•					
Fish-vertebrae	•	•					
Teeth, serrated edges	•	•					
Onychia	•	•					

Notes on the Foraminifera of Mineral Veins and the adjacent Strata.

By HENRY B. BRADY, F.L.S.

THE following "notes" on the Foraminifera obtained by Mr. Charles Moore in his investigations on the palæontology of mineral veins are necessarily incomplete. When presented there had been neither time nor opportunity for any close comparison of the specimens with the fossil Rhizopoda of periods immediately preceding and succeeding the horizon at which the veins occur. Hitherto the Foraminifera of the Carboniferous epoch have never been seriously studied, partly from the difficulty of obtaining rocks that can be disintegrated without injury to the fossil microzoa, and partly from the obscurity in which the early types are involved, owing to the obliteration of many of their structural peculiarities.

Under these circumstances it is not surprising that a large proportion of the specimens in the collection represent forms not previously described. Excepting those belonging to the genus *Involutina*, the Foraminifera are remarkable for their want of well-defined characters—zoological and physical causes having alike contributed to obscure the peculiarities they may have had when living.

The *Nodosariæ* are represented by examples of two forms, namely, a single specimen identical in contour with *Nodosaria rudicula*, Linné, sp., having well-defined subglobular chambers, and two or three shells having the general characters of *Dentalina pauperata*, D'Orbigny,—a cylindrical, slightly arcuate, and tapering test, with little or no constriction at the septa. The roughened and possibly partially sandy investment which all these specimens present, throws some difficulty in the way of placing them amongst the *Nodosariæ*; but inasmuch as the doubtfully arenaceous appearance may be due to the subcrystalline structure of the matrix on the one surface or the mineral infiltration of the chambers on the other, whilst in all morphological relations their characters are completely Nodosarian, separation from the group seems scarcely justifiable.

The *Textulariæ* in the collection are very irregular in their growth, and by no means constantly biserial. They resemble some of the varieties of *T. sagittula*, DeFrance, more than any other described species; but it may be necessary, or at least convenient, to assign a distinctive name to this primitive and variable form.

One or two obscure shells, regarded originally as *Tinoporos levis*, P. & J., are more probably a new species of *Involutina*, having an analogous acervuline mode of growth.

Some other minute and very obscure organisms in Mr. Moore's collection appear to be young examples of *Fusulina*, a genus of Carboniferous Foraminifera well known in its mature condition.

A number of bodies of larger size, shaped like sphaeros drawn out at two opposite portions of their periphery, and distinctly arenaceous in their structure, have been regarded as joints of a gigantic *Lituola*, pending material for more complete examination. The produced ends appear to have been slender stoloniferous tubes; and a number of the chambers may have been joined together, forming a moniliform test of some length*.

But the most interesting portion of the collection consists of the series of specimens of the genus *Involutina*, which place the relations of that type in

* Since the examination of the specimens from mineral veins, the author has learnt that the same fossil has been discovered in the Carboniferous Limestone of Northumberland by Sir W. C. Trevelyan. The anticipations above expressed are found in the main to be correct, but it has been thought necessary to separate the organism from *Lituola* proper, and the new generic term *Carteria* has been employed for it.

an entirely new light. The varieties of this genus described by M. Terquem from specimens found in the Lias formation of the north-east of France, comprised only a few outspread, discoidal, rotalian forms of finely arenaceous texture and variable septation—a series, in point of fact, structurally allied to *Trochammina*, but with some morphological resemblance to *Rotalia*.

The modifications, both in structure and mode of growth, exhibited in the forms about to be described, place the type on a much extended basis; and it will be seen how large a number of the simpler Foraminifera have their analogues in the varieties of this polymorphic genus.

So far from being, as hitherto supposed, an essentially Liassic type, the genus *Involutina* has its fullest and most characteristic development in the Carboniferous period.

Of already described species the following have been found in mineral veins and the adjacent stratified rocks:—

<i>Involutina Liassica</i> , Jones, sp.	<i>Involutina nodosa</i> , Terquem.
„ <i>polymorpha</i> , Terquem.	„ <i>aspera</i> , Terquem (?).
„ <i>silicea</i> , Terquem.	

In addition to these there are a large number of forms not before noticed, of which brief descriptions are now presented. The definition of their characters must be regarded as provisional to some extent, and founded on Mr. Moore's specimens. The elucidation of the type is as yet by no means complete; but, through the kindness of Mr. Young of Glasgow, Mr. Leipner, and Mr. W. W. Stoddart of Bristol, materials for more extended observations have been placed at the author's disposal, which will form the basis of a future memoir.

Genus INVOLUTINA, Terquem.

- I. cylindrica*, n. sp. Test elongate, cylindrical, arcuate, tapering; septation imperfect.
- I. incerta*, n. sp. Test biconcave, helicoid, the terminal portion leaving the spire at an angle; septation very obscure.
- I. recta*, n. sp. Test crozier-shaped; earlier chambers arranged spirally, later ones in a single straight series; chambers somewhat ventricose; septa constricted and well defined.
- I. lobata*, n. sp. Test lenticular, rotalian, lower surface sometimes concave; periphery rounded; chambers ventricose; septa constricted.
- I. radiata*, n. sp. Test nautiloid, lenticular; periphery sharp, subearinate; chambers long, narrow, often curved; septal lines not constricted, but in many cases marked by a radiate sutural limbation.
- I. crassa*, n. sp. Test rotalian, turgid, subglobose; chambers numerous, ventricose; terminal chamber especially large and inflated.
- I. obliqua*, n. sp. Test inequilateral, compressed, formed of long curved chambers, coiled irregularly on an oblique axis; septation indefinite; terminal chamber investing one-half of the shell.
- I. subrotunda*, n. sp. Test subspherical, formed by the acervuline growth of minute chamberlets on a central disk.

In addition to these, two other more obscure varieties have been met with, requiring further investigation. One of these, provisionally named *I. vermiciformis*, resembles *I. cylindroides*, but has a test of uneven diameter and irregular twisted contour, suggesting an uncoiled spiral with rudimentary septa. The other, *I. macella*, has a large complanate nautiloid test, the chambers marked by depressions, the septation very indistinct.

Report of the Rainfall Committee for the year 1868-69, consisting of
 C. BROOKE, *F.R.S.* (Chairman), J. GLAISHER, *F.R.S.*, Prof. PHILLIPS,
F.R.S., J. F. BATEMAN, *C.E.*, *F.R.S.*, R. W. MYLNE, *C.E.*, *F.R.S.*,
 T. HAWKSLEY, *C.E.*, Prof. ADAMS, *F.R.S.*, C. TOMLINSON, *F.R.S.*,
 Prof. SYLVESTER, *F.R.S.*, and G. J. SYMONS, *Secretary*.

THE attention of the Rainfall Committee has during the past year been largely devoted to various arrangements and details calculated to secure increased uniformity and accuracy amongst their observers; a very considerable number of stations have been visited during the past year by our Secretary, and the observers have been further instructed on any points in which their practice was incorrect; besides which the following code of rules has been drawn up for their guidance.

I. SITE.—A rain-gauge should not be set on a slope or terrace, but on a level piece of ground, at a distance from shrubs, trees, walls, and buildings—at the very least, as many feet from their base as they are in height. Tall-growing flowers, vegetables, and bushes must be kept away from the gauge. If a thoroughly clear site cannot be obtained, shelter is most endurable from N.W., N., and E., less so from S., S.E., and W., and not at all from S.W. or N.E.

II. OLD GAUGES.—Old established gauges should not be moved nor their registration discontinued until at least two years after a new one has been in operation, otherwise the continuity of the register will be irreparably destroyed. Both the old and the new ones must be registered at the same time.

III. LEVEL.—The funnel of a rain-gauge must be set quite level, and so firmly fixed that it will remain so in spite of any gale of wind or ordinary circumstance.

IV. HEIGHT.—The funnel of gauges newly placed should be 1 foot above grass.

V. RUST.—If the funnel of a japanned gauge becomes so oxidized as to retain the rain in its pores, or threatens to become rusty, it should have a coat of gas-tar or japan black.

VI. FLOAT GAUGES.—If the measuring-rod is detached from the float, it should never be left in the gauge. If it is attached to the float, it should be pegged or tied down, and only allowed to rise to its proper position at the time of reading. To allow for the weight of the float and rod, these gauges are generally so constructed as to show 0 only when a small amount of water is left in them. Care must always be taken to set the rod to the zero or 0.

VII. CAN- AND BOTTLE-GAUGES.—The measuring-glass should always be held upright; the reading is to be taken midway between the two apparent surfaces of the water.

VIII. TIME OF READING.—Nine A.M. daily; if only taken monthly, then 9 A.M. on 1st.

IX. DATE OF ENTRY.—The amount measured at 9 A.M. on any day is to be set against the previous one, because the amount registered at 9 A.M. of, say, 17th contains the fall during 15 hours of the 16th, and only 9 hours of the 17th. (*This rule, approved of by the Meteorological Societies of England and Scotland, cannot be altered, and is particularly commended to the notice of observers.*)

X. MODE OF ENTRY.—If less than one-tenth ($\cdot 10$) has fallen, the cipher must always be prefixed; thus, if the measure is full up to the seventh line, it must be entered as $\cdot 07$, that is, no inches, no tenths and seven hundredths.

For the sake of clearness, it has been found necessary to lay down an invariable rule that there shall always be two figures to the right of the decimal point. If there be only one figure, as in the case of one-tenth of an inch (usually written $\cdot 1$), a cipher must be added, making it $\cdot 10$. Neglect of this rule causes much inconvenience. All columns should be cast up *twice*. When there is no rain, a line should be drawn rather than ciphers inserted.

XI. CAUTION.—The amount should always be written down before the water is thrown away.

XII. SMALL QUANTITIES. The unit of measurement being $\cdot 01$, observers whose gauges are sufficiently delicate to show less than that, are, if the amount is under $\cdot 005$, to throw it away; if it is $\cdot 005$ to $\cdot 010$ inclusive, they are to enter it as $\cdot 01$.

XIII. Every observer should train some one as an assistant; but where this is not possible, instructions should be given that the gauge should be emptied at 9 A.M. on the 1st of the month, and the water bottled, labelled, and tightly corked, to await the observer's return.

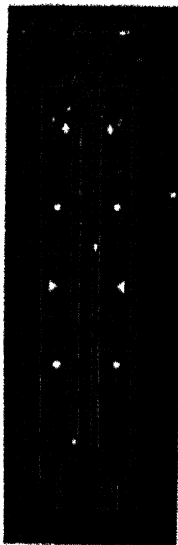
XIV. HEAVY RAINS.—When very heavy rains occur, it is desirable to measure immediately on their termination; and it will be found a safe plan, after measuring to return the water to the gauge, so that the morning registration will not be interfered with. Of course if there is the slightest doubt as to the gauge holding all that falls, it must be emptied, the amount being, in accordance with Rule XI, *previously* written down.

XV. SNOW.—In snow three methods may be adopted; it is well to try them all. (1) Melt what is caught in the funnel, and measure that as rain. (2) Select a place where the snow has not drifted, invert the funnel, and turning it round, lift and melt what is enclosed. (3) Measure with a rule the average depth of snow, and take one-twelfth as the equivalent of water. Some observers use in snowy weather a cylinder of the same diameter as the rain-gauge, and of considerable depth. If the wind is at all rough, all the snow is blown out of a flat-funnelled rain-gauge.

The desirability of more accurate information of the maximum fall of rain in the minimum time has recently been strongly felt. It will be supplied by the use of the instrument shown in figure 1. Its principle is very simple, consisting merely in the employment of a collecting area about twenty times that of the measuring-tube; an inch of rain is therefore expanded to a length of nearly 2 feet, and the rising rain-water in the tube carries on its surface a small white glass ball which renders the reading of the gauge visible from a considerable distance; an overflow pipe is also provided, by which the measurement is continued up to 2 inches.

In the year 1863 Mr. Symons read a short paper before the Mathematical Section of this Association, at the Newcastle-upon-Tyne Meeting, wherein he briefly notified the inauguration of the now well-known Calne rain-gauge experiments. The observations having been stopped in the year 1868, in consequence of the removal of Colonel Ward from Calne, considerable attention has been given to the discussion of the very voluminous record sheets. Those connected with the variation in the amount of rain collected at various heights above the ground are in the hands of the Rev. J. M. Du Port, M.A., for examination.

Fig. 1.



Our last Report contained particulars of the remarkable accuracy of the whole of the instruments; in the present we give the amounts collected by all the gauges in the magnitude series during the five years, an analysis thereof, and the results obtained at Calne, and an interim note on those indicated at Strathfield Turgis Rectory, Reading, to which, as explained in our last Report, the gauges were removed in the spring of 1868.

Table I. contains the monthly amounts for the whole period, Table II. is an abstract of the same; Table III. gives the ratio of the fall collected by each gauge to that collected by the gauge 12 inches in diameter, Table IV. is an abstract of the same.

TABLE I.—(Castle House, Calne, Wilts; lat. 51° 27' N., long. 1° 59' W.)

Magnitude Series 1 foot above ground. Depth of Rain collected.													
	1 in. up- right.	2 in. up- right.	4 in. upright.	5 in. up- right.	5 in. with flange.	6 in. up- right.	8 in. up- right.	12 in. up- right.	24 in. up- right.	5 in. square up- right.	10 in. square up- right.	5 in. square down pat- tern upright.	
1863.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	
August	2'572	2'706	2'852	2'762	2'890	2'866	...	2'921	2'913	2'638	2'903		
September ...	2'693	2'811	2'864	2'913	2'926	2'940	...	2'951	2'913	2'711	2'853		
October	3'255	3'411	3'458	3'473	3'478	3'529	...	3'540	3'509	3'217	3'483		
November ...	2'072	1'956	2'155	2'198	2'167	2'250	...	2'192	2'171	2'118	2'174		
December ...	'975	1'017	1'064	1'139	1'139	1'189	1'167	1'158	1'148	1'016	1'139		
1864.	11'567	11'901	12'393	12'485	12'600	12'774	1'167	12'762	12'654	11'700	12'552		
January	1'607	1'580	1'620	1'614	1'658	1'674	1'682	1'635	1'619	1'542	1'624		
February ...	'988	1'012	1'093	1'093	1'110	1'141	1'143	1'089	1'083	1'029	1'066		
March	2'366	2'453	2'545	2'533	2'554	2'566	2'574	2'487	2'398	2'398	2'483		
April	1'747	1'772	1'792	1'819	1'813	1'832	1'856	1'831	1'793	1'761	1'819		
May	1'008	1'032	1'099	1'104	1'110	1'119	1'119	1'088	1'072	1'043	1'084		
June	1'328	1'485	1'628	1'620	1'608	1'678	1'673	1'582	1'561	1'500	1'517		
July	'475	'565	'655	'647	'638	'679	'695	'661	'648	'637	'643		
August	'476	'552	'614	'653	'637	'692	'671	'618	'619	'604	'583		
September ...	2'405	2'465	2'586	2'609	2'651	2'700	2'713	2'583	2'543	2'458	2'544		
October	2'081	2'062	2'117	2'082	2'133	2'116	2'176	2'116	2'098	2'104	2'122		
November ...	1'695	1'688	1'784	1'767	1'806	1'855	1'880	1'834	1'829	1'785	1'810		
December ...	2'307	2'421	2'461	2'413	2'547	2'499	2'580	2'543	2'534	2'571	2'576		
1865.	18'483	19'087	20'014	19'954	20'265	20'421	20'754	20'054	19'886	19'432	19'901		
January	3'113	3'257	3'435	3'614	3'591	3'481	3'558	3'416	3'400	3'462	3'397		
February ...	2'715	2'768	2'729	2'738	2'907	2'833	2'901	2'839	2'860	2'863	2'815		
March	'741	'816	'891	'857	'893	'903	'936	'870	'862	'873	'857		
April	'632	'688	'719	'735	'738	'740	'738	'714	'706	'700	'705		
May	2'079	2'164	2'285	2'264	2'317	2'315	2'320	2'226	2'200	2'223	2'205	'647	
June	1'400	1'530	1'568	1'532	1'543	1'568	1'565	1'543	1'526	1'564	1'559	1'553	
July	2'622	2'751	2'857	2'871	2'909	2'965	2'946	2'823	2'842	2'817	2'796	2'924	
August	3'948	3'997	4'124	4'173	4'185	4'229	4'239	4'112	4'115	4'080	4'069	4'257	
September ...	'055	'106	'122	'130	'125	'141	'153	'120	'115	'118	'113	'158	
October	5'331	5'360	5'456	5'258	5'427	5'375	5'479	5'443	5'414	5'452	5'443	5'385	
November ...	3'073	3'087	3'165	3'209	3'174	3'316	3'134	3'195	3'195	3'133	3'186	3'348	
December ...	2'298	2'353	2'352	2'365	2'358	2'520	2'443	2'435	2'455	2'405	2'456	2'558	
	28'007	28'877	29'703	29'766	30'167	30'386	30'412	29'754	29'690	29'710	29'611		

TABLE I. (*continued*).

Magnitude Series 1 foot above ground. Depth of Rain collected.													
	1 in. up- right.	2 in. up- right.	4 in. upright.	5 in. up- right.	5 in. with flange.	6 in. up- right.	8 in. up- right.	12 in. up- right.	24 in. up- right.	5 in. square up- right.	10 in. square up- right.	5 in. square down put tern upright	
1866.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	
January	3'247	3'665	3'760	3'623	3'786	3'856	3'910	3'656	3'753	3'648	3'678	3'847	
February ...	3'683	3'925	4'119	3'977	4'051	4'186	4'193	4'068	4'145	4'001	4'047	4'219	
March	1'792	1'859	1'970	1'963	2'044	1'998	2'046	2'047	2'014	1'970	1'987	2'106	
April	1'910	2'029	2'156	2'206	2'224	2'218	2'230	2'145	2'126	2'117	2'114	2'204	
May	1'035	1'047	1'139	1'160	1'166	1'218	1'175	1'119	1'115	1'097	1'085	1'152	
June	2'805	2'845	2'976	2'985	3'014	3'046	3'077	2'927	2'974	2'916	2'845	3'025	
July	1'247	1'343	1'452	1'466	1'478	1'502	1'515	1'394	1'408	1'397	1'354	1'453	
August	2'052	2'188	2'395	2'419	2'423	2'481	2'513	2'332	2'342	2'292	2'241	2'440	
September ...	6'354	6'448	6'688	6'647	6'685	6'781	6'799	6'641	6'633	6'625	6'518	6'806	
October	2'007	2'028	2'101	2'108	2'126	2'117	2'146	2'098	2'118	2'083	2'082	2'183	
November ...	2'251	2'204	2'216	2'095	2'107	2'407	2'415	2'334	2'315	2'285	2'297	2'440	
December ...	2'867	2'737	2'782	2'859	2'890	3'049	3'027	2'941	2'974	2'837	2'958	3'064	
1867.	31'240	32'318	33'754	33'508	34'194	34'859	35'046	33'702	33'867	33'168	33'226	34'339	
January	3'146	3'370	3'404	3'268	3'591	3'448	3'545	3'441	3'784	3'417	3'519	3'458	
February ...	2'075	2'066	2'070	1'796	2'176	2'003	2'097	2'114	2'140	1'991	2'073	2'001	
March	2'361	2'965	3'042	3'135	3'140	3'055	3'068	3'192	3'117	2'920	3'118	2'885	
April	3'093	3'135	3'211	3'126	3'284	3'206	3'272	3'187	3'211	3'124	3'118	3'213	
May	1'788	1'740	1'820	1'819	1'828	1'867	1'851	1'765	1'818	1'755	1'695	1'798	
June	2'021	2'186	2'217	2'158	2'237	2'231	2'237	2'148	2'176	2'075	1'990	2'208	
July	3'442	3'691	3'733	3'733	3'806	3'756	3'803	3'645	3'661	3'530	3'511	3'693	
August	2'925	3'000	3'019	3'071	3'077	3'034	3'031	2'953	2'941	2'873	2'814	3'065	
September ...	1'720	1'727	1'773	1'771	1'801	1'792	1'818	1'760	1'758	1'667	1'630	1'735	
October	2'785	2'807	2'795	2'824	2'831	2'831	2'875	2'828	2'830	2'771	2'710	2'855	
November ...	1'228	1'200	1'225	1'308	1'300	1'313	1'298	1'282	1'268	1'269	1'251	1'318	
December ...	1'610	1'711	1'663	1'630	1'740	1'683	1'720	1'717	1'721	1'694	1'652	1'700	
	28'194	29'598	29'972	29'639	30'821	30'214	30'614	30'022	30'594	28'781	29'293	29'969	

TABLE II.—Strathfield Turgis Rectory, Winchfield, Hants; lat. 51° 20' N., long. 1° 3' W.

Magnitude Series 1 foot above ground.													
	1 in. up- right.	2 in. up- right.	4 in. up- right.	5 in. up- right.	5 in. with flange.	6 in. up- right.	8 in. up- right.	12 in. up- right.	24 in. up- right.	5 in. square up- right.	10 in. square up- right.	8 in. with flange.	
1868.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	
March, part of	4'50	4'89	5'15	4'82	5'00	4'82	5'08	5'02	5'35	4'70	4'72	5'14	
April	2'420	2'406	2'445	2'411	2'446	2'419	2'459	2'411	2'495	2'394	2'358	2'482	
May	8'34	8'78	9'17	9'23	9'37	9'41	9'11	9'19	9'60	8'99	8'88	9'39	
June	5'10	4'94	5'10	5'07	5'20	5'08	4'95	5'01	5'12	5'05	4'99	5'11	
July	2'063	2'028	1'939	1'818	1'934	1'886	1'943	1'916	1'896	1'944	1'903	1'966	
August	3'086	3'087	3'181	3'120	3'144	3'182	3'167	3'164	3'211	3'151	3'076	3'212	
September ...	3'494	3'537	3'550	3'506	3'558	3'570	3'539	3'553	3'687	3'464	3'344	3'597	
October	2'152	2'142	2'215	2'186	2'217	2'229	2'219	2'225	2'250	2'181	2'185	2'242	
November ...	1'714	1'738	1'782	1'737	1'780	1'747	1'807	1'752	1'834	1'758	1'790	1'810	
December ...	4'659	4'790	4'983	4'943	5'028	4'996	4'967	4'986	5'083	4'897	4'904	5'031	
Total	21'382	21'589	22'037	21'633	22'064	21'960	22'015	21'929	22'463	21'665	21'617	22'304	

TABLE III. Abstract. — Castle House, Calne, Wilts; lat. $51^{\circ} 27' N.$, long. $1^{\circ} 59' W.$

Magnitude Series 1 foot above ground Depth of rain collected.												
	1 in.	2 in.	4 in.	5 in.	5 in. with flange.	6 in.	8 in.	12 in.	24 in.	5 in. square.	10 in. square.	5 in. Snow- don pattern.
Part of 1863	11'45	11'20	11'19	11'48	11'6	11'74	...	11'76	11'64	11'70	11'52	...
1864	11'48	10'87	10'14	10'94	11'26	10'41	10'74	10'04	10'86	10'41	10'90	...
1865	10'07	10'87	10'7	10'76	11'36	10'16	10'41	10'74	10'66	10'71	10'61	...
1866	11'24	11'18	11'74	11'8	11'79	11'89	11'06	11'02	11'86	11'68	11'26	11'93
1867	11'19	10'58	10'54	10'69	10'81	10'14	10'14	10'22	10'59	10'78	10'29	10'69
Total 1863-67	117'49	111'78	111'81	111'13	111'07	111'66	...	111'19	111'69	111'79	111'31	...
Total 1864-67	105'94	105'80	111'44	111'86	111'47	111'82	111'86	111'11	111'17	111'09	111'01	...
Total 1866-67	10'44	61'91	61'76	61'17	61'05	61'71	61'60	61'74	61'46	61'99	61'59	61'08
Abstract — Strathfield Turgis, Wincfield, Hants.												
Part of 1868	11'18	11'58	11'07	11'61	11'04	11'60	11'05	11'91	11'46	11'66	11'67	...

TABLE IV. — Castle House, Calne, Wilts; lat. $51^{\circ} 27' N.$, long. $1^{\circ} 59' W.$

Magnitude Series 1 foot above ground. Ratio of the amounts collected.												
	1 in.	2 in.	4 in.	5 in.	5 in. with flange.	6 in.	8 in.	12 in.	24 in.	5 in. square.	10 in. square.	Range.
1863.												
August	38—	93	98	95	99	98			100+	90	99	12
September	91—	95	97	99	99	100+			99	92	97	9
October	92	96	98	98	98	100+			99	91—	98	9
November	95	89—	98	100	99	103+			99	97	99	14
December ...	84—	88	92	98	98	103+	101		99	88	98	19
1864.												
January	98	97	99	99	101	102	103+		99	94—	99	9
February ...	91—	93	100	100	101	105+	105+		99	95	101	14
March	96—	99	103	102	103	99	104+		100	97	100	8
April	95—	97	98	99	99	100	101+		98	96	99	6
May	93—	95	101	101	102	102	103+		98	96	99	10
June	84—	94	103	102	102	106+	106+		99	95	96	22
July	72—	85	99	98	97	103	105+		98	97	97	33
August	77—	89	103	106	103	112+	109		100	97	94	35
September ...	93—	95	100	101	103	105+	105+		98	96	98	12
October	98	97—	100	98	101	100	103+		99	99	100	6
November ...	93	92—	97	96	99	101	103+		100	97	99	11
December ...	91—	95	97	95	100	99	101+		100	101+	101+	10

The amount measured in this gauge has been taken as the standard of comparison = 100.

TABLE IV. (continued).

Magnitude Series 1 foot above ground. Ratio of the amounts collected.												
	1 in.	2 in.	4 in.	5 in.	5 in. with flange.	6 in.	8 in.	12 in.	24 in.	5 in. square.	10 in. square.	5 in. Snow- don't- upright. Range.
1865.												
January	91-	95	101	106+	105	102	104	Note.—The amount measured in this gauge has been taken as the standard of comparison = 100.	100	101	100	15
February ...	96-	98	96-	96-	102+	100	102+		101	101	100	6
March	85-	94	102	99	103	104	108+		99	100	98	23
April	88-	96	101	103	103	104+	103		99	98	99	91
May	93-	97	103	103	104+	104+	104+		99	100	99	99
June	91-	99	101+	99	100	101+	101+		99	101+	101+	101+
July	93-	97	101	102	103	105+	104		101	100	99	104
August	96-	97	100	101	102	103	103		100	99	99	104+
September ...	46-	88	102	108	104	118	127		96	98	94	132+
October	98	98	100	97-	100	99	101		99	100	100	105+
November ...	96-	96-	98	100	99	103	98		99	98	99	104+
December ...	94-	97	96	97	97	103	100		101	99	101	105+
1866.												
January	89-	100	103	99	104	105	107+	Note.—The amount measured in this gauge has been taken as the standard of comparison = 100.	103	100	101	105
February ...	91-	97	101	98	100	103	103		102	98	99	104+
March	88-	91	96	96	100	98	100		98	96	97	103+
April	89-	95	101	103	104+	103	104+		99	99	98	103
May	92-	94	102	104	104	109+	105		100	98	97	103
June	96-	97	102	102	103	104	105+		99	100	97	103
July	90-	96	104	105	106	108	109+		101	100	97	104
August	88-	94	103	104	104	106	108+		101	98	96	105
September ...	96-	97	101	100	101	102+	102+		100	98	98	102+
October	96-	97	100	101	101	101	102		101	99	99	104+
November ...	96	95	95	90-	99	103	104		100	98	99	105+
December ...	97	93-	95	97	98	104+	103		101	96	101	104+
1867.												
January	92-	98	99	95	104	100	103	Note.—The amount measured in this gauge has been taken as the standard of comparison = 100.	110+	99	102	101
February ...	99	98	98	85-	103+	95	100		102	95	99	95
March	74-	93	95	98	98	95	96		104	82	104	90
April	97-	98	101	98	103+	101	103+		101	98	98	101
May	101	99	103	103	104	106+	105		102	99	96-	102
June	94	102	103	101	104+	104+	104+		101	97	93-	103
July	94	101	102	102	104+	103	104+		100	97	96	101
August	99	102	102	104+	104+	103	103		99	97	95-	104+
September ...	98	98	101	101	102	102	103+		100	95	93-	101
October	99	99	99	100	100	100	102+		100	98	96-	101
November ...	96	94-	95	102+	101	102+	101		98	99	98	102+
December ...	94-	100	97	95	101+	98	100		100	99	96	99
Mean	91'4	95'6	99'7	99'6	101'5	102'6	103'6	100'0	100'0	97'1	98'3	14

TABLE V.—Strathfield Turgis Rectory, Winchfield, Hants; lat. 51° 20' N., long. 1° 3' W.

Magnitude Series 1 foot above ground. Ratio of the amounts collected.													
	1 in.	2 in.	4 in.	5 in.	5 in. with flange.	6 in.	8 in.	12 in.	24 in.	5 in. square.	10 in. square.	8 in. with flange.	Range.
1868.													
March, part of	90—	98	103	96	100	96	101	Standard of comparison.	106+	94	94	102	16
April	100	100	101	100	101	100	102		103+	99	98—	103+	5
May	91—	96	100	100	102	102	99		104+	98	97	102	13
June	102	99—	102	101	104+	101	99—		102	101	100	102	5
July	108+	106	101	99—	101	99—	101		99—	101	99—	103+	9
August	98	97—	100	99	99	100	100		101+	100	97—	101	4
September ...	98—	100	100	99	100	101	100		104+	98—	100	101	6
October	97	96—	100	98	100	100	100		101+	98	98	101+	5
November ...	98—	99	102	99	102	100	103		105+	100	102	103	7
December ...	93—	96	100	99	101	100	103		102+	98	98	101	9
Mean	97·5	98·5	100·5	98·7	100·6	100·3	100·4	...	102·5	98·8	98·6	101·7	8

TABLE VI. Abstract.—Castle House, Calne; lat. 51° 27' N., long. 1° 50' W.

Magnitude Series 1 foot above ground.												
	1 in.	2 in.	4 in.	5 in.	5 in. with flange.	6 in.	8 in.	12 in.	24 in.	5 in. square.	10 in. square.	5 in. Snow- don pattern in.
Part of 1863..	in. 90·6	in. 93·3	in. 97·2	in. 97·9	in. 98·8	in. 100·0	in. ..	in. ..	in. 99·1	in. 91·7	in. 98·5	
1864..	92·2	95·2	99·7	99·5	100·1	101·8	103·4	Standard of com- parison.	99·2	96·9	99·4	
1865..	94·3	97·1	100·0	100·1	101·4	102·2	102·2		99·8	99·9	99·5	
1866..	92·7	95·8	100·1	99·6	101·4	103·4	104·0		100·4	98·3	98·5	101·7
1867..	93·8	98·6	98·8	98·7	102·6	100·6	102·0		101·9	95·8	97·6	99·8
Average												
1863-67	93·1	96·5	99·7	99·3	101·4	101·9	..	..	100·4	97·3	98·7	
1864-67	93·3	96·8	100·0	99·4	101·7	102·1	102·9	..	100·5	97·9	98·7	
1866-67	93·4	97·3	100·0	99·2	102·1	102·2	103·1	..	101·2	97·3	98·3	101·9
Abstract. —Strathfield Turgis, Winchfield, Hants.												
Part of 1868.	97·5	98·5	100·5	98·7	100·6	100·3	100·4	..	102·5	98·8	98·6	

From these Tables it appears:—

(1) That the variation in this ratio for the same gauge in different months is often greater than that between different gauges in the same month.

(2) That (excluding the gauge 1 inch in diameter, which everywhere collects less *pro rata* than any other) the gauges while at Calne only differed

5·8 per cent., the largest quantity being recorded by those gauges which were most easily managed, viz. those 5, 6, and 8 inches in diameter.

(3) That at Strathfield Turgis the agreement has been still closer, all but the 1 inch and the 24 inch agreeing within 1·5 per cent.

This last result might partly have been anticipated from two causes,—

(a) Colonel Ward's health appears to have compelled him frequently to employ a substitute, and (b) Mr. Griffith commenced with the preliminary difficulties removed, and information as to possible sources of inaccuracy which previous experimentalists had had to discover by continuous observation.

Considering the absence of any trustworthy published observations upon the subject until those under notice were commenced, the lengthy articles published upon it in some of the scientific journals, and the almost universal ignorance upon it which recently prevailed, it is by no means an unimportant matter to have brought to a definite issue. Moreover, considering the various sizes of the gauges used simultaneously in different parts of the country, it is especially satisfactory to find that, instead of having, as was anticipated, a correction to apply to the observed values, when measured by a gauge of any but a standard size, to convert them into the equivalent indications of that standard size, no such correction is necessary; for all the most usual sizes, 5, 6, 8, and 12 inches diameter, agree within $1\frac{1}{2}$ per cent.

It seems probable that the small quantity registered by the 1-inch gauge is solely due to the great difficulty of emptying the last drop—by no means an unimportant matter with so diminutive a gauge, for a single grain weight of water corresponds to 0·008 inch, or nearly one ton of water per acre. The excess collected by the gauge 24 inches in diameter is probably explained by the influence of the large mass of metal of which it is composed; for after nights of heavy dew it generally contains more than any other, and this would naturally result from its greater radiating-power.

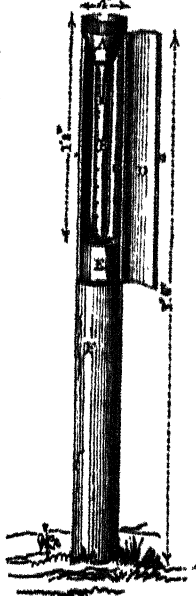
Some slight alterations were made at Strathfield Turgis, on January 1, 1869; and with their conclusion on January 1, 1870, the investigation there of the question of the influence of magnitude will probably be terminated.

The results of the examination of rain-gauges during the year are given in exactly the same form as in the last Report, and we are not aware that they call for any comment beyond referring, for explanation, to our Report for 1867, p. 466, and the plate there given. Gauge No. 278 being unlike any of those previously engraved, we add the annexed sketch, fig. 2. A is a funnel 4 inches in diameter, B a divided glass tube into which the rain passes. F a stout post, the upper part of which is hollowed out at C, half the outer portion, D, being hinged to afford access to the glass; E is a pad to keep B close up to A.

It will be noticed that the errors of some of the larger float gauges are not given in detail, the testing apparatus not being adapted to them.

It has been the practice of the Committee in their various reports to adopt, for convenience of comparison, a decennial grouping of returns, such as 1840–49, 1850–59, &c. We are now on the eve of completing one of these decennial periods, and it behoves us there-

Fig. 2.



fore to consider how we may best secure for the ensuing period the attainment of the objects for which we were originally appointed. One of these is expressed in the first grant in the following words:—"For the purpose of constructing and transmitting rain-gauges to districts where observations are not at present made."

Even to those least acquainted with the subject, it will be apparent how much more desirable, as well as easy, it is to compare simultaneous observations than those wherein both the observed values *and* their times are different. Your Committee have therefore felt it to be their duty to examine how far the existing stations adequately represent the true rainfall of the British Isles. The result shows that their number and distribution, though incomparably superior to that which existed when your Committee were appointed some years since, is still capable of great improvement; tracts of land the rainfall of which as water-supply for towns is of high importance are without adequate observations, while other places are, if possible, too well provided.

To take Devonshire as an example; excepting two gauges at the Convict Prison, one on the northern edge at Chagford, and one on the south at Lee Moor Clay Works, Dartmoor (that wettest of Devonshire districts) has no representative, Exmoor has none at all, and there is no gauge between Torquay and Plymouth. On the other hand, Sidmouth has four or five observers, and Exeter an equal number.

Similar cases of unequal representation occur in various parts, and should be removed. The Tyne-side Naturalists' Club are about to establish a series of gauges along the Cheviots, the Cardiff Naturalists' Society are doing the same in South Wales, and other instances could be quoted.

We have already shown that there is a special reason for endeavouring to equalize the representation during the ensuing autumn, so that the new observers whom we hope to obtain may have a few months' practice before the commencement of the decennial period 1870-79.

We hope that the landed proprietors of Great Britain and Ireland are becoming sufficiently aware of the importance of rainfall statistics in engineering and draining operations to see their own advantage in helping us by having observations regularly made by careful persons under their own supervision. There are, however, some districts for which your Committee will have not only to provide the instruments but also to pay some small fee to the observers. To meet this special charge we have to ask for a special grant, in addition to the small ordinary one required for current expenses in the examination of gauges and other kindred matters.

EXAMINATION OF

Reference number.	Date of examination.	COUNTY. Station. OWNER. Observer.	Construction of gauge.	Maker's name.	Time of reading.	Height of gauge.	
						Above ground.	Above sea-level.
	1868.					ft. in.	feet.
264.	Sept. 4.	NORFOLK. Thorpe Hamlet Parsonage, Norwich. MRS. COOKE. Mrs. Cooke.	XI	Negretti & Zambra	9 a.m.	1 0	11
265.	Sept. 4.	NORFOLK. Thorpe, Norwich. W. BIRKBECK, ESQ. W. Birkbeck, Esq.	III	Casella	9 a.m.	1 0	137
266.	Sept. 4.	NORFOLK. St. Catherine's Close, Norwich. C. EVANS, ESQ. C. Evans, Esq.	XII	Casella	10 a.m.	2 2	123
267.	Sept. 5.	NORFOLK. East Dereham. G. H. COOPER, ESQ. G. H. Cooper, Esq.	X	Negretti & Zambra	week-ly.	1 3	161
268.	Sept. 5.	NORFOLK. Honingham. THE LADY BAYNING. The Lady Bayning.	III	Knight	9 a.m.	0 9	88
269.	Sept. 7.	NORFOLK. Mattishall Vicarage. THE REV. J. M. DU PORT. The Rev. J. M. Du Port.	X	Negretti & Zambra	9 a.m.	1 3	165
270.	Sept. 7.	NORFOLK. Hookering. THE REV. M. J. ANDERSON. The Rev. M. J. Anderson.	X	Negretti & Zambra	9 a.m.	1 3	140
271.	Sept. 8.	SUFFOLK. Gisleham, Lowestoft. THE REV. H. JODRELL. The Rev. H. Jodrell.	III	Casella	9 a.m.	1 3	36
272.	Sept. 11.	SUFFOLK. Carlton Colville, Lowestoft. G. EDWARDS, ESQ. G. Edwards, Esq.	X	Negretti & Zambra	month-ly.	0 8	6
273.	Sept. 12.	NORFOLK. Geldeston, Brecles. E. T. DOWSON, ESQ. E. T. Dawson, Esq.	XII	Casella	9 a.m.	1 1	30
274.	Sept. 14.	SUFFOLK. Somerleyton Hall, Lowestoft. SIR F. CROSSLEY, BART.	X	Negretti & Zambra	7 a.m.	3 0	60

RAIN-GAUGES (*continued from last Report*).

Diameters (that marked M = mean).	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and an- gular elevation of objects above mouth of rain- gauge.	Remarks on position &c.	Reference number.
	Scale- point.	Grains.				
in.	in.		in.			
5'01	'1	500	—'001	E. House 40°.	On lawn, sloping slightly to W.,	264.
5'00	'2	1000	—'002		good position.	
5'00	'3	1500	—'003			
4'99	'4	1980	+ '001			
M 5'000	'5	2480	correct.			
5'02	'1	504	—'002	S.S.W. Fir 25°.	On crest of hill, sloping gently to	265.
4'98	'2	1020	—'006		the Yare in S.	
5'00	'3	1510	—'005			
5'00	'4	2020	—'007			
M 5'000	'5	2520	—'008			
5'00	'01	50	correct.	S.W. Tree 25°.	On dwarf post on large lawn.	266.
5'00	'10	500	—'001			
4'98	'20	1000	—'002			
5'01	'30	1490	—'001			
M 4'998	'40	1980	correct.			
	'50	2480	—'001			
8'02				N.E. Fir 32°.	On slight mound on lawn; ground	267.
7'98					level. Observer absent and mea-	
8'00					suring-glass not accessible.	
8'02						
M 8'005						
5'00	'1	495	correct.	N.W. Angle of	On edge of flower-bed; ground	268.
5'00	'2	990	correct.	House 55°.	level.	
5'00	'3	1520	—'007			
5'00	'4	2020	—'007			
M 5'000	'5	2520	—'008			
7'98	'01	80	+ '004	E. Trees 45°.	In kitchen garden, somewhat shel-	269.
8'02	'1	1260	+ '001	S.E. " 45°.	tered; ground level.	
8'02	'2	2550	+ '001	S.W. " 25°.		
7'98	'3	3830	+ '002			
M 8'000	'4	5030	+ '004			
8'00	'01	127	correct.	N. Trees 60°.	On lawn, surrounded by trees; to	270.
7'98	'1	1250	+ '001	N.E. " 60°.	be moved to another position	
8'00	'2	2560	—'002	E. " 60°.	where nothing will rise 30°	
8'00	'3	3820	—'001	S.W. " 40°.	above gauge except one tree in	
M 7'995	'4	5050	+ '002		S.E.	
5'00	'1	500	—'001	N.E. Trees 40°.	In kitchen garden, and rather	271.
5'00	'2	1050	—'012	S.W. " 22°.	sheltered.	
5'00	'3	1520	—'007	N.W. " 40°.		
4'99	'4	2030	—'012			
M 4'997	'5	2510	—'006			
8'00	'1	1340	—'006	S.W. Rose-bush	Open position, except as noted;	272.
7'96	'2	2550	—'001	50°.	ground level and as noted in other	
8'01	'3	3910	—'009		columns; gauge only 6 ft. above	
8'00	'4	5050	+ '001		mean sea-level, and therefore	
M 7'992	'5	6330	correct.		only 3 ft. above high-water mark.	
5'00	'01	50	correct.		Very good open position in ter-	273.
5'00	'10	500	—'001		racead garden.	
5'00	'20	1000	—'002			
4'99	'30	1490	—'001			
4'998	'40	1980	correct.			
	'50	2480	—'001			
8'03	'1	1300	—'002		Gauge fixed on a stool in centre of	274.
8'00	'2	2550	—'001		large lawn; quite open.	
8'00	'3	3850	—'003			
7'98	'4	5080	correct.			
M 8'003	'5	6310	+ '003			

EXAMINATION OF

Reference number.	Date of examination.	COUNTY. Station. OWNER. Observer.	Construction of gauge.	Maker's name.	Type of reading.	Height of gauge.	
						Above ground.	Above sea-level.
275.	1868. Sept. 14.	SUFFOLK. Somerleyton Rectory, Lowestoft. THE REV. C. J. STEWARD. The Rev. C. J. Steward.	III	Cary	9 a.m.	ft. in. 0 3	feet. 56
276.	Sept. 14.	SUFFOLK. Hopton Hall, Lowestoft. C. CORY, ESQ.	X	Negretti & Zamboni		0 3	47
277.	Sept. 15.	SUFFOLK. Acle, Yarmouth. THE REV. R. W. KENNION. The Rev. R. W. Kennion.	X	Negretti & Zamboni		0 7	40
278.	Sept. 16.	NORFOLK. Ranham. THE REV. E. GILLET. The Rev. E. Gillett.	See Fig. p. 300	Sawyer	9 a.m.	6 3	31
279.	Sept. 17.	NORFOLK. Filly, Yarmouth. MR. G. CRISP. Mr. G. Crisp.	XI	Negretti & Zamboni	9 a.m.	2 4	11
280.	Oct. 27.	HAMPSHIRE. Strathfield Turgis Rectory, Winchester. G. J. SYMONS, ESQ. The Rev. C. H. Griffith.	XII	Casella	9 a.m.	1 0	209
281.	Oct. 27.	HAMPSHIRE. Strathfield Turgis Rectory, Winchester. G. J. SYMONS, ESQ. The Rev. C. H. Griffith.	III	Bryson	9 a.m.	1 0	209
282.	Nov. 2.	NOTTINGHAM. Highfield House, Nottingham. E. J. LOWE, Esq., F.R.S.	X	Negretti & Zamboni	10 a.m.	15 0	.....
283.	1869. Mar. 27.	HAMPSHIRE. Wote Street, Basingstoke. T. SWEETING, ESQ. T. Sweeting, Esq.	XII	Appl	9 a.m.	1 0	265
284.	Mar. 27.	HAMPSHIRE. Eastlands, Basingstoke. G. STEPHENS, ESQ. G. Stephens, Esq.	III	Wheeler	9 a.m.	1 0	300
285.	April 7.	YORKSHIRE. Saddleshworth Station. L. & N.-W. RAILWAY. The Station Master.	VI	Crosley	monthly.	5 0	640

RAIN-GAUGES (*continued*).

Diameters (that marked M = mean).	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and an- gular elevation of objects above mouth of rain- gauge.	Remarks on position &c.	Reference number.
	Scale- point.	Grains.				
in.	in.		in.			
5'00	'1	500	- '001	.....	In kitchen garden, open position ;	275.
5'01	'2	1000	- '001		suggested its being raised a little	
5'02	'3	1500	- '002		to avoid in-splashing.	
5'03	'4	2000	- '002			
M 5'038	'5	2500	- '003			
8'00	'1	1290	- '001	S.E. Tree 32°.	Sunk in a large pot, on lawn ;	276.
8'00	'2	2600	- '005		quite clear, except as noted.	
7'98	'3	3940	- '011			
8'00						
M 7'995						
8'00	'1	1260	correct.	N.E. Laburnum	On edge of carriage drive, and	277.
8'01	'2	2580	- '004	55°.	near a light iron railing.	
7'99	'3	3850	- '004	S.W. House 32°.		
8'03	'4	5130	- '006			
M 7'985	'5	6380	- '004			
4'03	'1	300	+ '004	N.E. Trees 50°.	In garden, position not the best	278.
4'02	'2	600	+ '012	S.W. " 28°.	available ; suggested removal	
4'00	'5	1550	+ '015	N.W. " 50°.	on January 1, 1863.	
4'00	'10	3150	+ '014			
M 4'012						
5'02	'1	500	- '001	N. House 54°.	Very much sheltered ; to be raised	279.
4'98	'2	1000	- '001	S.E. Trees 30°.	3 ft., which will make it nearly	
5'01	'3	1500	- '002	N.W. " 47°.	clear.	
5'00	'4	1990	- '001			
M 5'003	'5	2480	correct.			
3'01	'1	160	+ '010	.....	In experimental rain-gauge en- closure ; clear of everything.	280.
3'00	'2	350	+ '004			
3'00	'3	540	- '002			
2'99	'4	720	- '004			
M 3'000	'5	900	- '004			
4'69	'1	450	- '004	.....	Close to No. 280.	281.
4'65	'2	900	- '008			
4'68	'3	1345	- '012			
4'66	'4	1800	- '016			
M 4'670	'5	2250	- '024			
7'87					On N.E. parapet of house. Glass	282.
8'02					not measured.	
7'83						
7'96						
M 7'920						
5'02	'1	520	- '004	S.E. Pear 55°.	Part of pear tree will be cut off ;	283.
5'00	'2	1020	- '004		position will then be very good.	
5'01	'3	1500	correct.			
5'04	'4	2010	- '003			
M 5'017	'5	2510	- '003			
5'00	'1	500	- '001	W. House 32°.	In kitchen garden ; ground level,	284.
5'00	'2	1000	- '001		and position good.	
5'02	'3	1500	- '002			
5'00	'4	1990	- '001			
M 5'005	'5	2480	+ '001			
9'97				.....	On a stone column on the top of	285.
9'97					a railway-cutting ; nearly level	
9'98					with the chimnies of the station.	
9'96						
M 9'970						

EXAMINATION OF

Reference number.	Date of examination.	COUNTY Station. ON THE RIVER.	Gauge.	Maker's name.	Height of gauge.	
					Above ground.	Above sea level.
286.	1869. April 7.	YORKSHIRE. Friedland Viaduct, Greenfield. <i>THE R.R. G. FENABLES.</i> <i>The R.R. G. Fenables.</i>	M	Negretti & Zamboni	ft. in 4 6	feet. 457
287.	April 7.	YORKSHIRE. Standedge. <i>L. & N.W. RAILWAY.</i>	I	.....	month- ly.	2 0 1150
288.	April 8.	YORKSHIRE. Harden Moss, Meltham. <i>HUDDESFIELD WATER WORKS.</i>	X	Negretti & Zamboni	1 0	1200
289.	April 8.	YORKSHIRE. Bilberry Reservoir, Holmfirth.	I	.....	month- ly.	1 6 800
290.	April 8.	YORKSHIRE. Boshow Wharves.	I	.....	month- ly.	1 9 950
291.	April 8.	YORKSHIRE. Holme Styes Reservoir, Holmfirth.	I	.....	2 0	850
292.	April 8.	YORKSHIRE. Dunford Bridge Reservoir. <i>DEWSBURY WATER WORKS.</i> <i>Mr. G. Whitfield.</i>	II	Newman ?	2 0	1100
293.	April 8.	YORKSHIRE. Dunford Bridge Station. <i>M. S. & L. RAILWAY.</i>	VIII	Casartelli	8 1/2 A.M. 3 2	954
294.	April 8.	YORKSHIRE. Charlton. <i>M. S. & L. RAILWAY.</i>	VIII	Casartelli	9 A.M. 3 0	1075
295.	April 9.	YORKSHIRE. Meltham Grange. <i>HUDDESFIELD WATER WORKS.</i>	X	Negretti & Zamboni	1 1	925
296.	April 9.	YORKSHIRE. Scope, Meltham. <i>E. C. GOODDY, ESQ.</i> <i>Mr. J. Taylor.</i>	VIII	Casartelli	Var. 3 8	1125

RAIN-GAUGES (*continued*).

Diameters (that marked M = mean).	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and an- gular elevation of objects above mouth of rain- gauge.	Remarks on position &c.	Reference number.		
	Scale- point.	Grains.						
in.	in.		in.					
5'02	'1	490	+ '002	E. Church 42°.	Fixed on dwarf post in the garden, which is somewhat shut in by the railway embankment; ground hilly.	286.		
5'02	'2	970	+ '006	S. House 28°.				
5'00	'3	1460	+ '008	W. Trees 30°.				
5'04	'4	1955	+ '009					
M 5'020	'5	2460	+ '008		Very exposed position on a slight slope, but nothing rises more than 5° above the gauge, which is <i>very</i> much weather-worn.	287.		
8'05			nearly correct.					
8'03								
8'05								
7'98					On level piece of moor, quite ex- posed, but surrounded by a 5-ft. iron hurdle fence 6 ft. square. Glass not accessible.	288.		
M 8'028								
7'96								
8'12								
7'99					On a flat bank on a steep hill-side facing S.W. Orifice so large as unduly to facilitate evapora- tion.	289.		
8'01								
M 7'995			correct	N.E. Wall and rising ground 21°.				
8'02								
7'98					In a flat field E. of the reservoir; very open. When visited the top was not properly on the cylinder, and much loss must have resulted.	290.		
8'01								
M 8'000			correct					
6'92								
0'97					In a box made of inch-wood, the sides of which being level with the rim of the gauge produce in splashing. The orifice of the gauge being very large will compensate for this error. Hilly ground.	291.		
6'95								
6'94								
M 6'945								
7'00					On west end of embankment, very exposed position.	292.		
6'80								
6'92								
6'62								
M 6'835			correct		A short distance E. of station, on flatish ground. Hills rise to a considerable height in N.E.	293.		
11'81								
12'02								
11'93								
12'01					In field. The box holding this gauge was tilted nearly 5° to S.W., and had been so for some little time; had it levelled.	294.		
M 11'943								
8'48	'1	1400	+ '002	N.N.E. Tree 33°.				
8'50	'2	2760	+ '007					
8'46	'3	4200	+ '006					
8'50	'4	5550	+ '011					
M 8'485	'5	7000	+ '011		Good position in large flat field. (Glass not accessible).	295.		
8'55	'1	1430	correct.					
8'46	'2	2780	+ '005					
8'42	'3	4150	+ '009					
8'48	'4	5570	+ '009		Near the centre of the moor, slight ridge in W.S.W., but its eleva- tion only 10°. Position good.	296.		
M 8'478	'5	7050	+ '005					
7'83								
8'02								
7'98								
8'10								
M 7'982								
8'50	'1	1460	- '002					
8'51	'2	2900	- '003					
8'48	'3	4310	- '001					
8'50	'4	5700	+ '002					
M 8'498	'5	7050	+ '008					

EXAMINATION OF

Reference number.	Date of examination.	COUNTY. Station. <i>OWNER.</i> <i>Observer.</i>	No. of gauges.	Maker's name.	Height of gauge.	
					Above ground.	Above sea level.
297.	1869. April 9.	YORKSHIRE. Broadstone Reservoir. <i>DEWSBURY WATER WORKS.</i>	II	.....	ft. in.	feet
298.	April 9.	YORKSHIRE. Ingthorpe. <i>BARNSELY LOCAL BOARD.</i> <i>Mr. Brown.</i>	X	Negretti & Zambra	1 0	950
299.	April 9.	YORKSHIRE. Penistone Station. <i>M. & L. RAILWAY.</i>	VIII	Chasartelli	9 a.m. 3 6	717
300.	April 14.	YORKSHIRE. Redmires. <i>SHEFFIELD WATER WORKS CO.</i>	X	Negretti & Zambra	4 3	1100
301.	April 14.	YORKSHIRE. Redmires. <i>SHEFFIELD WATER WORKS CO.</i>	VI	Watkins & Hill.	4 3	1100
302.	April 15.	LANCASHIRE. Blackstone Edge <i>ROCHDALE CANAL COMPANY.</i>	I	 monthly.	2 6	1200
303.	April 15.	YORKSHIRE. Longwood Reservoir. <i>HUDDERSFIELD WATER WORKS.</i>	VI	.....	4 11	600
304.	April 16.	YORKSHIRE. Fartown, Huddersfield. <i>CAPT. CHICHESTER.</i> <i>Capt. Chichester.</i>	III	Casella	9 a.m. 0 8	300
305.	April 16.	YORKSHIRE. Dalton, Huddersfield. <i>J. W. ROBSON, ESQ.</i> <i>J. W. Robson, Esq.</i>	XI	Negretti & Zambra 9 a.m.	0 3	350
306.	April 16.	YORKSHIRE. Dalton, Huddersfield. <i>J. W. ROBSON, ESQ.</i> <i>J. W. Robson, Esq.</i>	X	Negretti & Zambra 9 a.m.	0 3	350
307.	April 19.	MIDDLESEX. Grove House, Tottenham. <i>C. ASHFORD, ESQ.</i> <i>C. Ashford, Esq.</i>	III	Smith & Beck ... 9 a.m.	2 0	.....

RAIN-GAUGES (*continued*).

Diasteters (that marked M=mean).	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and an- gular elevation of objects above mouth of rain- gauge.	Remarks on position &c.	Reference number.
	Scale- point.	Grains.				
in.	in.		in.			
12'02					Gauge lenky, and not in use, level with reservoir bank.	297.
11'98						
12'10						
12'01						
M 12'002						
8'06	'1	1200	+ '004	W. House 20°. N. Tree 40°.	In cottage garden N. of reservoir; country gently undulating.	298.
7'82	'2	2520	- '001			
7'93	'3	3770	correct.			
8'01	'4	5050	- '002			
M 7'955	'5	6290	- '001			
8'50	'1	1350	+ '006		Gauge tilted $\frac{3}{4}$ of an inch to S.E.; position bad, being close to the top corner of a wall which drops 25 ft. abruptly below the gauge.	299.
8'50	'2	2850	+ '001			
8'50	'4	5700	+ '001			
8'46	'5	7040	+ '008			
M 8'490						
8'00	'1	1300	- '003		In garden on N. bank of reservoir, rather exposed.	300.
8'00	'2	2600	- '005			
8'00	'3	3810	correct.			
8'00	'4	5050	+ '002			
M 8'000	'5	6260	+ '007			
10'00					15 ft. E. of No. 300.	301.
10'00						
10'00						
10'00						
M 10'000						
10'00					On west side of the Edge, in a very exposed part of the moor. Mea- suring-rod absent; apparently a good gauge.	302.
10'05						
10'01						
9'98						
M 10'010						
10'00					At S.E. corner of lower reservoir bank; rapid fall to E. and S.	303.
9'88						
9'94						
10'00						
M 9'955						
5'00	'1	495	correct.	S.W. House 35°.	In garden N.E. of house, open position, undulating ground.	304.
4'99	'2	980	+ '002			
4'99	'3	1490	- '001			
5'00	'4	1980	correct.			
M 4'995	'5	2450	+ '005			
4'98	'1	490	+ '001	N.E. Hedge 30°.	In level and rather sheltered gar- den.	305.
5'03	'2	1000	- '002			
5'00	'3	1510	- '005			
5'00	'4	2000	- '003			
M 5'002	'5	2500	- '004			
8'00	'1	1350	- '007	N.E. Hedge 30°.	Close to No. 305.	306.
7'99	'2	2500	+ '003			
8'02	'3	3820	- '001			
8'00	'4	5120	- '003			
M 8'003	'5	6300	+ '004			
5'02				S.W. Apple 42°.	In large garden rather full of trees; no better position. Testing-glass broken. To be revisited.	307.
5'00						
4'98						
5'02						
M 5'005						

EXAMINATION OF

Reference number.	Date of examination.	COUNTY. Station. ON SITE. Observer.	Maker's name	Height of gauge
308.	1869. May 3.	DERBYSHIRE. Woodhead Station. M. S. & L. RAILWAY. Station Porter.	VIII Casartelli	10 m. 4 6 feet 87.8
309.	May 3.	CHESHIRE. Woodhead Reservoir. MANCHESTER WATER WORKS.	XII	9 6 9 0 6 850
310.	May 3.	CHESHIRE. Woodhead Reservoir. MANCHESTER WATER WORKS.	II Newman	6 a.m. 0 10 680
311.	May 4.	CHESHIRE. Torrside. MANCHESTER WATER WORKS.	II Newman	7 a.m. 1 6 600
312.	May 4.	CHESHIRE. Rhodes Wood Reservoir. MANCHESTER WATER WORKS.	II Newman	6 a.m. 1 0 520
313.	May 17.	MIDDLESEX. Squires Mount, Hampstead. R. FIELD, ESQ. R. Field, Esq.	III Private	9 a.m. 1 0 380
314.	May 17.	MIDDLESEX. Squires Mount, Hampstead. R. FIELD, ESQ. R. Field, Esq.	III Casella	9 a.m. 1 0 380
315.	May 17.	MIDDLESEX. Squires Mount, Hampstead. R. FIELD, ESQ. R. Field, Esq.	III Casella	9 a.m. 1 0 380
316.	May 17.	MIDDLESEX. The Grove, Hampstead. H. SHARPE, ESQ. H. Sharpe, Esq.	XII Casella	9 a.m. 50 0 470
317.	May 17.	MIDDLESEX. The Grove, Hampstead. H. SHARPE, ESQ. H. Sharpe, Esq.	XII Apps	9 a.m. 2 0 440
318.	July 5.	HAMPSHIRE. Highfield Park, Winchester. H. MARSON, ESQ. H. Marson, Esq.	XII Apps	9 a.m. 1 6 250

RAIN-GAUGES (*continued*).

Diameters that marked M = mean.	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and angular elevation of objects above mouth of rain gauge.	Remarks on position &c.	Reference number.
	S. dis- point	Grains.				
in.	in.	in.				
8'50	1	1450	1		On slight mound, in gorge, 300 yards W. of W. entrance to the Woodhead Tunnel.	308.
8'50	2	2850	1			
8'50	3	4250	+0.3			
8'50	4	5650	+0.50			
M 8'500	45	6450	correct.		Near keeper's house, Woodhead reservoir; on ground sloping to S.W.	309.
5'02	1	470	+0.5			
4'94	2	980	1			
5'00	3	1490	+0.2			
4'98	4	1990	0.4		In valley near the reservoir; quite open; rod attached.	310.
M 4'985	5	2460	+0.1			
11'95			nearly cor- rect, but see remarks.			
12'05						
12'00						
11'93					In valley near keeper's house; good position.	311.
M 11'983			correct.			
12'02						
12'01						
12'02					Open situation in valley, running E.W.; rod attached, and rim curved.	312.
M 12'017			nearly correct.			
12'02						
11'94						
12'00					The grounds being much wooded, this and the two following gauges are so arranged that from what- ever point the rain has fallen, one of the gauges will be unin- fluenced thereby, and the ob- servations are tabulated accord- ingly.	313.
M 11'993						
5'00	1	498	correct.	N. Bush 40°.		
5'00	2	990	correct.	E. Trees 73°.		
5'02	3	1500	-0.03	W. Trees 38°.	N. Bushes 40°. N.E. Elms 58°. W. Poplars 46°.	314.
4'98	4	1990	-0.01			
M 5'000	5	2480	correct.			
5'02	1	498	correct.			
4'98	2	990	correct.		N. Trees 58°. E. Elms 42°. S.W. Poplars 88°.	315.
5'03	3	1500	-0.02			
4'98	4	1990	-0.01			
M 5'002	5	2480	correct.			
5'00	1	498	correct.		On corner of gallery surrounding tower of house; very exposed position.	316.
5'00	2	990	correct.			
5'00	3	1500	-0.03			
5'00	4	1990	-0.01			
M 5'000	5	2480	correct.		In small garden, rather shut in by walls and trees.	317.
5'00	1	498	-0.01			
5'00	2	998	-0.01	N.E. Wall 28°. S.E. Tree 40°. S. Shed 32°.		
5'00	3	1500	-0.003			
5'00	4	2000	-0.03		In level garden; very good posi- tion except as noted.	318.
M 5'000	5	2480	correct.			
5'03	1	495	+0.01	S.W. Apple 41°.		
5'00	2	1000	correct.			
5'03	3	1500	-0.01			
5'00	4	2005	-0.02			
M 5'015	5	2500	-0.01			

EXAMINATION OF

Reference number.	Date of examination.	COUNTY. Station. OWNER. Observer.	Construction of gauge.	Maker's name.	Time of reading.	Height of gauge.	
						Above ground.	Above sea-level.
319.	1869. July 8.	BERKSHIRE. Forbury Gardens, Reading. BOARD OF HEALTH. Mr. Davis.	XI	Negretti & Zambra	9 a.m.	ft. in. 1 1	feet. 150
320.	July 8.	BERKSHIRE. Russell Street, Reading. DR. WORKMAN. Dr. Workman.	III	Knight	9 a.m.	1 6	159

Interim Report of the Committee on the Laws of the Flow and Action of Water containing Solid Matter in Suspension, consisting of T. HAWKSLEY, PROFESSOR RANKINE, F.R.S., R. B. GRANTHAM, Sir A. S. WAUGH, F.R.S., and T. LOGIN.

Your Committee considered, in the first place, what experiments would be necessary in order to furnish the data required for the determination of the laws of the flow and action of water containing solid matter in suspension, and what would be the probable cost of these experiments. Their estimate of that cost was £5000, and they came to the conclusion that this was beyond the means of the Association. They had no authority to apply to the Government in the name of the British Association; but in their individual capacity they addressed a memorial to Her Majesty's Secretary of State for India, representing the practical value of such experiments, and especially their importance to the interests of India. That memorial was accompanied by a general description of the experiments required, and an estimate of their cost; and copies of all these documents are appended hereto. The Government, however, declined to accede to the application.

Your Committee beg leave to represent that, if reappointed, and invested with power to apply to the Government in the name of the British Association, their future application might meet with better success.

APPENDIX.

I. Flow of Water with Solid Matter in Suspension.

Sketch of proposed Course of Experiments.—1. It is proposed to apply for the temporary use of a piece of ground near London, and, if possible, in the neighbourhood of the Kew Observatory.

2. A canal to be constructed with a smooth bottom and sides of plate glass about 500 feet long, 5 feet broad, and 3 feet deep, and capable of being covered when required.

3. At one end of the canal will be a reservoir supplied with water by means

RAIN-GAUGES (*continued*).

Diameters (that marked M = mean).	Equivalents of water.		Error at scale-point specified in previous column.	Azimuth and an- gular elevation of objects above mouth of rain- gauge.	Remarks on position &c.	Reference number.
	Scale- point.	Grains.				
in.	in.		in.			
4'98	'1	500	—'001	S. Wellingtonia 38'.	In the gardens near the station ; good position.	319.
5'01	'2	1000	—'002			
5'00	'3	1480	+ '001			
5'00	'4	1975	+ '001			
M 4'997	'5	2480	—'001	S.W. Apple 51'.	In garden in rear of house on slight bank, and sheltered as noted ; no material improvement in po- sition practicable, except by cut- ting down one or two good trees.	320.
4'98	'1	500	—'001			
5'02	'2	1010	—'002			
4'98	'3	1505	—'004			
5'01	'4	2020	—'008			
M 4'998	'5	2505	—'006			

of a small pumping steam-engine, and containing mechanism for diffusing solid matter of different kinds in the water.

4. The water will be made to flow along the canal at first pure, and then with different proportions of different kinds of solid matter in suspension, and with different depths of current.

5. Observations will be made of:—

A. The declivity of the surface of the water.

B. The velocity of the current at the surface, bottom, sides, and in-
termediate points, also the mean velocity.

C. The mode of motion of the particles as seen through the plate-glass
sides of the trough.

D. The rate at which solid matter is either deposited or swept away
by the current under various circumstances.

E. The temperature of the water.

F. The direction and velocity of the wind when the trough is exposed
to it.

6. Experiments to be made to determine the quantities of solid matter
contained in samples of water taken from different points in the length, breadth,
and depth of the trough.

7. Observations and experiments to be made with the inner surface of the
trough roughened in various ways.

8. Also with weirs and other obstacles of different forms and in different
positions.

9. The results of the observations and experiments to be compared with
those of observations (so far as these have been recorded) made upon actual
rivers and on the great scale.

10. The whole results to be submitted to mathematical analysis, in order to
deduce general laws and practical rules from them.

11. The rough estimate of the outlay required for materials, work, and pay
of assistants and workmen till the next Meeting of the British Association
is £1500.

This is exclusive of the pay of the engineer from the Public Works De-

partment of India, to whom it is proposed to entrust the superintendence; but it is believed that the entire series of experiments and investigations will not exceed £5000.

II.

To His Grace The Duke of Argyll, K.T., Her Majesty's Secretary of State for India. The Memorial of Thomas Hawksley, Civil Engineer, Vice-President of the Institution of Civil Engineers; Major-General Sir Andrew Scott Waugh, Knight; William J. Macquorn Rankine, Civil Engineer, Regius Professor of Civil Engineering and Mechanics in the University of Glasgow; Richard Boxall Grantham, Civil Engineer, Member of the Institution of Civil Engineers; and Thomas Login, Civil Engineer, Member of the Institution of Civil Engineers.

Showeth,—That your Memorialists respectfully solicit Your Grace's attention to a subject of great importance in the construction of artificial rivers for irrigation and drainage.

That at a Meeting of the British Association in August last at Norwich, a paper was read by Mr. Login, one of your Memorialists, on the abrading and transporting power of water, in which he laid before the Association the results of his experience in India regarding the power of flowing water for holding solid matter in suspension.

The subject was considered to be of so much practical importance, that your Memorialists were appointed a Committee to report upon it to the Mechanical Section of the British Association; but they have found the present state of scientific knowledge to be so vague and imperfect that it is in their judgment necessary to obtain, in the first instance, a complete series of experimental data.

To institute experiments would, however, require some expenditure for apparatus and attendance beyond the means of the Association.

Moreover, since the results of the investigations would, in the opinion of your Memorialists, be of great public utility, they venture, independently of the Association and solely in their individual capacities, to lay this matter before Your Grace in the hope that the Indian Department of Her Majesty's Government will take the subject matter of this Memorial into their consideration, and if deemed expedient direct that the requisite investigation may be undertaken at the public expense.

(Signed)

T. HAWKSEY, V.P. Inst.C.E.

ANDREW SCOTT WAUGH, Major-Gen. R.E., F.R.S.

W. J. MACQUORN RANKINE, C.E., LL.D., F.R.S.

RICHARD B. GRANTHAM.

T. LOGIN.

Interim Report by the Committee on Agricultural Machinery, consisting of the Duke of Buccleuch, F.R.S., The Rev. PATRICK BELL, DAVID GREIG, J. OLDHAM, WILLIAM SMITH, C.E., HAROLD LITTLEDALE, The Earl of CAITHNESS, F.R.S., ROBERT NEILSON, Professor RANKINE, F.R.S., F. J. BRANWELL, Rev. Professor WILLIS, F.R.S., and CHARLES MANBY, F.R.S.; P. LE NEVE FOSTER and J. P. SMITH, Secretaries.

THIS Committee have to report that several of its members have been engaged in collecting and arranging the information necessary in order to

enable a final report to be prepared; but that, in consequence of the great extent and variety of the subjects to be reported on, and the very recent date of the trial of implements by the Royal Agricultural Society, and by the Highland Agricultural Society of Scotland, on the results of which trials the Report must to a great extent be based, it has been found impossible to complete a final Report in time for the present Meeting. A short Report upon reaping-machines has been furnished by Mr. Oldham; but the Committee consider it advisable to defer publishing it until it can be included in a general Report, especially as some important trials of reapers have been made since it was written.

Your Committee beg leave to represent that, if reappointed, they are confident of being able in due time to present a satisfactory Report to the Association.

Report on the Physiological Action of the Methyl and Allied Series.

By BENJAMIN W. RICHARDSON, M.A., M.D., F.R.S.

IN introducing the present Report to the Association, I would, as preliminary to new matter of research, record that the substance known as bichloride of methylene (the properties of which I was led to study as a part of the work entrusted to me in previous years) has, during the past twelve months, increased very greatly in practical importance. The bichloride has been used for general anaesthesia on a large scale in Guy's, the London, Charing Cross, Ophthalmic, and Samaritan Hospitals. It has also been largely employed for the same purpose in the provinces of England. In France its action has been carefully studied, and one of the graduation theses at Strasbourg has been devoted to the subject of its action. In Italy the bichloride has made its way, and in Germany it is employed by the distinguished Von Graefe (who learned its application from Dr. Taylor of Nottingham), and by several other eminent surgeons.

Respecting the action of the bichloride of methylene and its advantages over other anaesthetics as yet discovered and rendered applicable, I have received special reports from the following gentlemen: - Peter Marshall, Esq., Administrator at the Charing Cross Hospital, Dr. Junker, Administrator at the Samaritan Free Hospital, J. Rendle, Esq., Administrator at Guy's, J. Adams, Esq., of the London Hospital, J. Bader, Esq., Ophthalmic Surgeon at Guy's, Dr. Taylor, Surgeon to the Ophthalmic Hospital of Nottingham, and Mr. Wood of Brighton.

I am happy to add that up to this date (August) no accident has occurred in the administration of the bichloride. I have never held that it is free from danger, and I reported in regard to it, at first, that it could not be considered as the safest agent of its kind until it had been administered twenty thousand times with a totality of less than ten deaths as the result. I hope, however, now that it may even go safely through this very severe ordeal; for at the lowest estimate it has been administered 4500 times in England alone without a fatal catastrophe. In the experience which has sprung from the administration of this anaesthetic, one very interesting and valuable practical truth has come forth, viz. that with skill on the part of the administrator the most rapid and safest insensibility can be induced with a quantity not exceeding sixty minims; thus for small operations, or, I had better said, short operations, such as tooth-extraction, operation for cataract, &c., the required anaesthesia

can be induced in from twenty to forty seconds, with perfect recovery in from three to five minutes. The mode of administering, in order to produce these effects, is simple: the inhaler I showed last year is modified by being lengthened, and the fluid is not introduced as spray, but is poured directly into the inhaler. The inhaler itself is made of leather, and is lined with loose demette; it is perforated at the end furthest removed from the mouth, so as to admit air. For this modification of inhaler, and for demonstrating the extremely rapid action of the bichloride with it on the human subject, we are indebted to Mr. Rendle. The method has been successfully employed now in four hundred operations. I may be pardoned for dwelling on this practical fact for one reason alone; for this reason, that it shows the true value of a correct theory in estimating the properties of chemical substances on living animal bodies, based on the physical characters, purely, of the substances themselves. From the chemical composition of the bichloride of methylene, from its boiling-point, and the density of its vapour, I was able to claim for it its probable place as an anæsthetic before it was subjected to the test of experience, and especially to claim for it that its power to take effect would be as rapidly developed as would be the recovery from it when it was withdrawn. The practice has proved the theory to have been in this case safely founded; and the fact may be accepted as an encouragement to all who are or may be striving to reduce our knowledge of the action of medicinal agents to fixed principles. For my part I am certain (and I think the after pages of this Report will help to prove the idea) the day is at hand when the mere chemical and physical characters of any substance being known to the physiologist, he will be able to foresee clearly what are the physiological values of the substance, and to calculate the symptoms and changes it will induce in the animal economy from pure theoretical formulas and with perfect precision.

METHYLAL.

The substance methylal, $C_2H_4O_2$, to which I called attention last year, deserves another brief word. I confirm what I said concerning it last year, viz. that it is a slowly acting anæsthetic, producing by its inhalation a sleep which is very deep and prolonged. I would add to this Report that methylal may be taken internally in the same proportion as common ether (it could be used also in the form of hypodermic injection), and that, as it is soluble in water, it promises to be a very valuable addition to our list of anodyne remedies. During the past months Liebreich of Berlin has brought out the substance chloral (C_2HCl_3O) as a body which possesses the power of inducing long-continued sleep. I have not yet been able to obtain chloral for experiment*.

PLAN OF NEW RESEARCHES.

In the new researches to which I have devoted my attention since last Meeting, I have aimed, while studying the action of several compounds which have not previously been considered by the physiologist, to bring the present work, together with the past, into systematic arrangement, to group under their proper chemical heads the agents submitted to inquiry, and to ascertain whether any distinctive physiological characteristics could be discovered as connected with distinct chemical series of organic bodies. I commenced, therefore, by placing before myself a set of Tables which I now put before the

* After the reading of this Report Dr. Richardson was supplied, at Exeter, with a specimen of chloral by Daniel Hanbury, Esq. He was thus enabled, at the request of the Section, to bring up a supplementary report on chloral during the Meeting.

Section. I have grouped in these Tables certain representatives of different series in their natural place and in five divisions, viz. nitrites, hydrides, alcohols, chlorides, and iodides. Under each division the two first representatives of the series are tabled, and the fourth and fifth. The propylic compounds, which would form the third representatives, are omitted in every case, owing to the difficulty of obtaining perfectly reliable specimens. The substances named in italics have been considered in previous Reports.

	Name.		Chemical composition.	Vapour-density, $H_2=1$.	Specific gravity. Water 1000.	Boiling-point.		Percentage of iodine in iodides.
	Old.	New.				C.	F.	
HYDRIDES.	<i>Methyl</i> ...	Protylen	$C_2 H_3 H$	8	Gas.	.....	.....	
	<i>Ethyl</i> ...	Deutylene	$C_2 H_3 H$	15	Gas.	.....	.....	
	<i>Butyl</i> ...	Tetrylen	$C_4 H_9 H$	29	Gas.	.....	.....	
	<i>Amyl</i> ...	Pentylen	$C_5 H_{11} H$	36	625	30	86	
NITRATES.	<i>Methyl</i> ...	Protyl...	$C_2 H_3 NO_2$	30.5	Gas.	.....	.....	
	<i>Ethyl</i> ...	Deutyl...	$C_2 H_3 NO_2$	37.5	917	18	64	
	<i>Butyl</i> ...	Tetryl...	$C_4 H_9 NO_2$	51.5	.....	64	147	
	<i>Amyl</i> ...	Pentyl...	$C_5 H_{11} NO_2$	58.5	877	96	205	
ALCOHOLS.	<i>Methylie</i> ...	Protylic	$C_2 H_3 O$	16	814 at 0° C.	60	140	
	<i>Ethylie</i> ...	Deutylie	$C_2 H_3 O$	23	792 at 16° C.	78	172	
	<i>Butylie</i> ...	Tetrylic	$C_4 H_9 O$	37	803 "	110	230	
	<i>Amylie</i> ...	Pentylic	$C_5 H_{12} O$	44	811 "	132	270	
CHLORIDES.	<i>Methyl</i> ...	Protyl...	$C_2 H_3 Cl$	25.25	Gas.			
	<i>Ethyl</i> ...	Deutyl...	$C_2 H_3 Cl$	32.25	921 at 0° C.	11	52	
	<i>Butyl</i> ...	Tetryl...	$C_4 H_9 Cl$	46.25	880 at 16° C.	70	158	
	<i>Amyl</i> ...	Pentyl...	$C_5 H_{11} Cl$	53.25	.....	102	216	
IODIDES.	<i>Methyl</i> ...	Protyl...	$C_2 H_3 I$	71	2.240 at 16° C.	42	108	89.4
	<i>Ethyl</i> ...	Deutyl...	$C_2 H_3 I$	78	1.946 "	72	162	81.4
	<i>Butyl</i> ...	Tetryl...	$C_4 H_9 I$	92	1.604 "	120	248	69.4
	<i>Amyl</i> ...	Pentyl...	$C_5 H_{11} I$	99	1.511 "	146	295	64.1

While in this manner studying the various substances in great groups, I have tried also to study peculiarities of action in members of the same group, with special reference, in each case, to the effect of the aggregation of carbon and increase of weight.

To these observations I have been able to add others, which refer to the individual peculiarities of some special compounds; and when those peculiarities have suggested a practical and useful application, I have noted the facts with care, and embodied them in my remarks.

Lastly, as in the course of my research many opportunities were offered of studying the dangers in the administration of some of the chemical bodies named in the Table, I took advantage of such opportunities to test by experiment the best means of counteracting those dangers when they occur. This therefore forms a concluding and special part of the present Report.

In preparing for experiments, certain rules were followed which it is right at once to name.

In all cases where the substance to be examined was a gas, it was administered by inhalation; in cases where the substance was a very volatile liquid, it was administered by inhalation chiefly; and in cases where the substance was less easily volatilizable, it was administered not merely in the form of vapour, but either by the mouth or by subcutaneous injection.

As it soon became apparent that, under all forms of administration, the results were materially modified by temperature, care was taken to secure, in analogous experiments, the same ranges of temperature. This was effected by means of specially constructed chambers, into which the air could be admitted in measured quantities, and in which the air or atmosphere could be maintained for any length of time at a nearly fixed degree, the variations at the extremest being under three degrees in Fahrenheit's scale. (The chamber was defined in a diagram. In it the air could be raised to 120° Fahr. and sustained at that heat, or reduced to 10° below freezing-point and kept at that low temperature steadily.)

Another chamber was also used in experiments where inhalation of an atmosphere charged with a foreign gas or vapour was not wanted; this consisted of a simple metal chamber with a double lining, through which warm or cold air could be passed at pleasure. Within it was slung a cradle lined with thick felt, made after the manner of a hammock. In this chamber the air could be readily raised to a temperature of 160°, or even 200° Fahr.; but the chamber was not air-tight, and was not adapted for holding in circuit atmospheres of common air mixed with vapours or gases. It was always well ventilated with pure air, and was used for inducing recovery, or for proving the conditions adverse or favourable to recovery from certain of the agents employed when they were administered in excess.

The classes of animals subjected to the vapours or fluids were batrachians, birds, small herbivorous and carnivorous mammals. In every instance where comparative inquiries were made the utmost care was taken to estimate mere apparent differences of phenomena from the same agent from differences in the character or constitution of the animal submitted to the action of the agent. The natural temperatures of all the warm blooded animals was recorded from time to time, and the mean temperature was calculated and adopted as the natural standard.

Advantage was taken of different seasons of the year, and of extreme natural variations of heat and cold, for the carrying on of many of the inquiries. This point of practice, followed out at first without reference to any other than the present research, was found to have a distinct and important bearing on the general question of the use and administration of chemical medicinal agents.

I now pass to the first part of this Report, taking up the study of the groups of substances in the order of the Tables.

PART I.—THE NITRITE SERIES.

In previous Reports I have called the attention of the Section to the action of the nitrites of methyl, ethyl, and amyl. I have experimented during the past year with the nitrite of butyl, and have thus completed the elementary study of the group up to the amyl or pentylic series. The specimen of nitrite of butyl I used was made for me by Professor Wanklyn. It is obtained by the action of nitrous acid upon butylic alcohol.

Nitrite of butyl is a slightly coloured fluid, having an odour like nitrite of amyl, but it is not so overpowering. Its physiological action is nearly the same as that of nitrite of amyl, but less intense and protracted; it quickens the pulse, produces suffusion of the countenance, causes great oppression on the brain, and those singular noises or sounds in the head which resemble the sounds produced by the rushing of water. The breathing also is affected, and the respiratory muscles are influenced as after running sharply until out of breath. In a case where a young friend of mine (who has naturally a

very hard and quick pulse) inhaled the nitrite, I noticed, during the time when the face was suffused, that the pulse, which previously had been beating at 80 per minute, did not rise to more than 86 beats, but became much relaxed and even feeble, regaining its tone within a few seconds after the agent was withdrawn. For practical purposes, the nitrite of butyl presents to me no advantages over the nitrite of amyl, and it has the disadvantage that it is more easily decomposed.

GENERAL REVIEW OF THE NITRITES IN REGARD TO PHYSIOLOGICAL ACTION.

With these observations on nitrite of butyl we may, I think, consider that the physiological properties of the nitrites is, in an elementary sense at least, understood. They all present a beautiful unity of action, varied only in increasing force and persistency of action as the weight of each representative in the series increases with and from increase of carbon. The summary of their action is briefly as follows: they act instantaneously on the nervous system of organic life, reducing the power or force of that system, and reducing, as a result, the vascular tension; thus they cause relaxation of extreme vessels, and that suffusion of blood which is the most prominent visible sign of their effect; thus they cause intense action of the heart, followed by quickened respiration, due to the liberation of the heart from the tension to which it is normally subject; thus, administered internally, they cause (and this is specially the case with nitrite of ethyl or nitric ether) free secretion of organs, such as the kidneys, which are under the control of the organic nervous centres.

Acting in the manner thus stated on the vascular tension, they produce an action on the voluntary muscles and on the brain, leading to paralysis of muscular and mental power, when carried to extremity. But this paralysis is in every sense a secondary action of the nitrites; they produce no anaesthesia showing primary action in the cerebral organs; they cause no convulsion of the voluntary muscles showing primary action on the cerebrum, cerebellum, or spinal cord. Unconsciousness and muscular prostration, when they follow, are due to destruction of organic nervous control over the vessels which supply the great nervous centres with blood; and the final general prostration is syncope, syncope as pure as that emotional syncope which awaits fear or intense anger, or the equivalent of these, sudden loss or removal of blood from the centres of volitional power.

I hope I do not seem to press these facts unduly; for in reality, when the whole question is seen by the experimental physiologist, it cannot be too strongly urged. In the organic nitrites we hold in our hands a series of chemical agents which exert an influence over a specific set of organs in animal bodies, and over those organs in one specific way. Further, these agents, against our wills, act through precisely the same means and in precisely the same manner as do the more obscure, because more refined, influences which excite daily in us what we call emotions. An act which shall call forth a blush, an act which shall call forth the pallor of terror, an act which shall produce involuntary secretion, an act which shall make the heart beat with an intensity that is painfully felt,—all and any of these acts, which would be called psychical, have their precise physical analogues in the actions of the organic nitrites. In this study the physiologist meets the psychologist on common ground; his facts as to effects from the physical cause are as sure as are facts from the effects of mental causes; but how either the physical or the psychical impression is made remains yet to be discovered. It may in either case be an immediate impression conveyed by the nervous expanses of the

senses direct to the organic nervous sympathetic chain. It may be in either case an indirect impression conveyed from within the body, and, as one would imagine by the blood, to that nervous chain. But why the nervous chain should thereupon lose its controlling power, what molecular change is communicated to it to make it lose its power, we cannot answer at present. We must be content to wait, satisfied for the moment with the possession of a truth which fifty years ago the most sanguine physiologist would not have dreamed of, that there is a class of organic bodies by which we are able to induce, in a simple physical way, what have been called up to this time emotional phenomena.

One other observation deserves a moment's expression, inasmuch as it explains a well-known symptom which many persons have experienced. If the heart be thrown into sudden action by any external cause, by breathing, for example, the vapour of nitrite of amyl, there is produced in the head a peculiar pulsating burring sound, which sometimes amounts to a whistle or coo. In some forms of disease, especially in debility following upon emotional distress or anxiety, this sound becomes persistent and intensely distressing. In both cases the sound is produced by the same cause. The vascular tension reduced at those points of the body where the vessels pass through rigid canals or openings, there is vibration set up in the resistant parts, which vibration produces audible sound. In the entrance of the internal carotid artery into the skull by the carotid canal, we have a perfect arrangement for the production of this pulsating murmur; and as the canal is in close and solid connexion with the organ of hearing, the murmur is clearly and often painfully audible whenever the artery (if I may use the expression) is not under guard, *i. e.* is not under the full control of the organic nervous power.

THE PHYSIOLOGICAL ACTION OF HYDRIDES.

The first of the hydrides named in the Table, and the last, have been studied in regard to their physiological action and values.

Hydride of Methyl or Protyle.—This body, known commonly as fire-damp in mines, and as marsh-gas on land, is made by heating together acetate of soda, caustic potassa, and well-dried limo. Its properties and composition will be seen in the Table. I have already (at Dundee) reported on the action of this hydride and have little to add to what was there recorded. To make it produce rapid anaesthesia the gas must be inhaled nearly undiluted with air. It produces no excitement, and recovery from its effects, if the inhalation be stopped in time, is extremely rapid: a few seconds are, indeed, sufficient to restore consciousness and muscular power. The gas can only kill by a process of gradual negation of respiration, by replacing air required for the oxidation of the blood. It has no irritating properties, and is breathed without causing spasm. I repeat here what I was able to state at Dundee, that death from fire-damp must be of the easiest kind, must in fact be as easy as going to sleep, a circumstance which accounts probably for the sleep-like placidity and posture in which the dead have been found after fatal accidents from inhaling this substance. From the circumstance that the hydride is found in the air of marshes, it has been taxed as the cause of malarious fevers. There is no evidence whatever to support this view—no evidence whatever that the gas is anything more than an immediate and simply negative poison, the effects of which cease so soon as the animal body has been removed from its influence. It is certainly possible that a person exposed for several hours to the gas mixed with air would be reduced in power, and would suffer from

reduction of temperature; but from this he would recover, if there were no other conditions acting injuriously at the same time. It is fair, therefore, to assume that in the atmosphere which generates malarial fever, the hydric is only a coincident with the true cause of fever, and that either dampness or the presence of some other organic poison is at work to produce the more serious and persistent consequences of exposure to marsh-air.

Hydride of methyl in the pure state might be used as nitrous oxide is often used, viz. to produce insensibility to pain by gaseous suffocation; but the principle of the method is rude and unworthy of science.

Hydride of Amyl.—Hydride of amyl may be made by adding iodide of amyl to water with zinc, and applying heat at 288°F. ($=142\frac{2}{3}^{\circ}\text{C.}$) for some hours. On distillation a fluid comes over composed of amylene and the hydride; the mixture is left in contact with caustic potassa for twenty-four hours, and is then rectified from a water-bath at 35°C. The distillate is immersed in a freezing-mixture, and treated with anhydrous and fuming sulphuric acid, which retains the amylene, and the hydride is distilled over. This, which is Frankland's process, is described in full in Watt's Chemical Dictionary; but to get by this plan any sufficient quantity of fluid for a series of physiological researches would be practically out of the question. Fortunately the hydride forms one of the parts of American petroleum, and from a specimen of this petroleum Dr. Versmann has been able to distil for me a sufficient quantity of the fluid for my purposes. The specimen presents all the characteristics of the hydride; the specific gravity is 0.625, and it boils at 86°F. ($=30^{\circ}\text{C.}$). As a fluid it is colourless and odourless; it is very agreeable to breathe, and creates no irritation. There is a specimen before the Section.

A distillation from petroleum, having all the properties of hydride of amyl, was tried in America about two years ago as a general anæsthetic, and was reported on favourably. I therefore subjected the hydride to careful experiment, and found it to be truly a general anæsthetic that might admit of practical application. In order to produce decided effects, 40 per cent. of the vapour of the hydride must be present in the inspired air; and so volatile is the fluid that constant repetition of it is necessary, unless it be placed in a receiver admitting very little air. Administered by inhalation to pigeons, in sufficient quantity to produce determinate insensibility, the period required for the production of symptoms was found to be under a minute, and the insensibility to be profound in a period a little less than two minutes. The insensibility in the bird is attended with some convulsive movement and drawing back of the head. Recovery from the effects of the hydride is rapid, not so rapid as in the case of the hydride of methyl, but still rapid, the animal regaining its full consciousness and muscular power within two minutes. The temperature of the body remains nearly unchanged. The inclination is towards a reduction of temperature, but it does not exceed the fourth of a degree on Fahrenheit's scale. The blood undergoes no obvious change.

To observe the extreme effects of the hydride, animals, after they had become insensible, were allowed to sleep into death. The process of death is gentle, and the respiration and circulation cease nearly simultaneously, the respiration failing a little first. The temperature of the body falls during the last few minutes of life from 1° to $1\frac{1}{2}^{\circ}$ of Fahrenheit's scale. The pupil dilates. After death the heart is found well charged with blood on both sides, and the organ on exposure to the air starts into vigorous action. The blood on the left side is darkened in colour, but the coagulation is natural, and the corpuscles are uninfluenced. The lungs, as is common when both sides of

the heart are left full of blood, are natural in colour; they are not blanched, as after chloroform, nor congested, as after ether. The brain is natural. The muscular irritability is long retained.

To put the hydride to further test, I inhaled the vapour of it myself from a Vulcanite inhaler, such as I employ for bichloride of methylene: the vapour was very agreeable to breathe, caused no cough and no irritation, but a sensation as of a gentle warmth or glow in the chest. After six inspirations I felt evidences of change in the cerebral circulation, giddiness, and inability to stand, with the common swaying movement, or sense of movement, which marks the first degree of anæsthetic sleep. In a little time I lost consciousness for a few moments; but the inhaler being removed I quickly recovered, and in three minutes was perfectly well. Neither nausea, nor headache, nor chilliness followed.

Owing to the low boiling-point of this hydride, it admits of being employed by the physiologist for many inquiries bearing on the restoration of animal life after some forms of death. Thus, after destroying in frogs, by the action of extreme cold, those functions or acts which constitute what is called life, the process of recovery is best determined by regulating the slow restoration or return of heat, and by preventing a suddenness of reaction which ordinarily is fatal. Now, by immersing the animal in the hydride of amyl, and then warming, there is no danger of warming too quickly, as the fluid boils at 86° Fahr.; neither is there any necessity for removing the animal until, by the escape of a bubble of gas from the mouth, the first indications of restoring respiration are afforded; then the animal removed will, in most cases, recover in the open air. I have seen the frog recover after immersion under this hydride for a period of seven minutes.

On the whole, I am of opinion that pure hydride of amyl might, if it were needed, be employed as a general anæsthetic, and that, for short operations especially, it would be effective. I do not, however, put it above the other anæsthetics, but would rather assign to it the same position as belongs to ethylic ether, amylene, and nitrous oxide gas.

I must not, however, pass over some other minor but, in the aggregate, important uses of this agent. At a very moderate cost now, a hydride may be obtained which, though not absolutely answering to its pure chemical character, is sufficiently pure for the purposes I shall name, and which must, when the value of it is made known, ensure, I think, its employment by all practitioners of the healing art. I will notice some of its applications in detail, but by no means all of them.

From the fact that the hydride boils at a temperature twelve degrees below the natural temperature of the human body, it is very useful as a fluid for producing, in form of spray, rapid local insensibility. In most persons it produces insensibility, in this manner, in a period of from one to two seconds, and for mere punctures or slight incisions it answers well; but for larger essays it is too volatile, and does not cover a sufficient surface. It is advisable, therefore, to dilute it with absolute ether, by which means the best compound that can be employed for producing rapid local insensibility is secured.

The hydride of amyl dissolves some juices and fats with great facility. Camphor and spermaceti dissolve in it freely, and the vegetable and animal oils mix with it. Advantage may be taken of these properties for making a solution I have placed before the Section, and which is most valuable for relieving the pain of burns. The solution is made by saturating the hydride with spermaceti, then adding camphor until that ceases to dissolve, and finally

mixing the compound which has been produced with an equal quantity of olive-oil. When this solution is applied on wool, over a burned surface, the cold produced by the evaporation of the hydride gives instant relief; while the thin layer of fatty substance left behind effectually excludes the air, and forms a false pellicle or skin, which greatly promotes cure.

Iodine dissolves readily in the hydride, as is seen in another solution which is before us. The solution thus formed is the best of all solutions of iodine, for a variety of purposes; when the solution is applied to the skin, the hydride passes away at once, and the iodine is left in a thin and even layer. The solution is also useful for deodorizing; for this purpose pieces of cloth may be saturated in it, and when the iodine is deposited on the fabric it may be suspended in the air, when the iodine is quickly diffused mechanically, but evenly, through the air. Iodine inhalation, weak solutions of the compound being used, may be readily and elegantly applied by means of this compound.

If strong solution of ammonia be well shaken with hydride of amyl, and then allowed to stand, small bubbles of gas are steadily evolved, and after a time the hydride containing a large quantity of ammonia may be decanted off; this ammoniated hydride is an excellent antiseptic, and can be used with advantage by the anatomist for the preservation of animal structures in the fresh state in a closed jar. The same solution charged with camphor can be used by the student of natural history as a preservative of his specimens. Lastly, the ammoniated hydride can be applied medicinally by inhalation in cases where the physician wishes to administer ammonia rapidly, as in scarlet fever and in states of great prostration. The ammonia can be so diluted in this manner as to be rendered agreeable for inhalation.

I could enumerate other uses of the hydride of amyl, but must pass them by with the further remark that, so soon as its value is known and appreciated, it must become as common an agent in medicine as ammonia, or ether, or alcohol.

REVIEW OF THE HYDRIDES.

Reviewing the action of the class of hydrides up to the hydride of amyl, we may consider each body of the series to be, in a physiological sense, negative in character. Very stable as chemical compounds, practically insoluble in the blood, boiling at a lower temperature than the living body, producing no irritation, they inflict no injury on the living economy unless they are inhaled in such quantities as to exclude air. Then they produce, like amylene, a temporary insensibility, their power in this respect increasing with the increase of the carbon in the series: but, owing to the insolubility of the agents in the blood, the insensibility is in all cases of very brief duration, and would quickly be a fatal insensibility if, by continuous administration, it were prolonged.

THE ALCOHOL SERIES.

METHYLIC ALCOHOL.

At the Meeting at Dundee I reported at length on the action of methylic alcohol. I have now to add to the Report then made respecting it some observations in relation to its influence on the animal temperature. In its effects, in this particular, methylic alcohol resembles chloroform, but in a more striking degree. In birds (pigeons) I found, when the third degree of intoxication was produced, that in so short a period as ten minutes the temperature was reduced four degrees Fahr., and that the decline of temperature continued during the whole period of recovery, reaching at the lowest a decline of eight degrees on Fahrenheit's scale. The temperature begins to

rise about two hours after the first indications of recovery; but a period of from seven to eight hours is required to restore the body, even under favourable conditions, to the natural temperature. In one case these effects of reduction of temperature were observed when the external temperature of the air was 80° Fahr. ($26\frac{2}{3}^{\circ}$ C.).

ETHYLIC ALCOHOL.

Much research has been made of late years on the physiological action of ethylic or common alcohol, much controversy has followed research, and points unsettled are too numerous to mention. Feeling it quite impossible to enter into one point of controversy without involving myself in many others, I determined simply to make one or two new and independent inquiries, and to place on record the results. What I have done relates to the influence exerted by alcohol on animal temperature, the condition of the organs of the body during extreme alcoholic intoxication, and the mode of death when the poison is carried to the fatal degree.

On the particular points of temperature, I have to record that in the progressive stages of alcoholic intoxication; the tendency in all cases is to a decrease of animal heat. In the progress towards complete intoxication under alcohol, however administered, there are, as under chloroform, four distinct degrees or stages. The first is a stage of simple exhilaration, the second of excitement, the third of rambling insensibility, and the fourth of entire unconsciousness, with muscular prostration. The duration of these stages can be modified in the most remarkable manner by the mode of administration; but whether they are developed and recovered from in an hour or a day, they are always present except in cases where the quantity of alcohol administered is in such excess that life is endangered or instantly destroyed. In the first or exhilarative stage the temperature undergoes a slight increase; in birds a degree Fahrenheit, in mammals half a degree. With the stage of excitement, in the second stage, during which there is vomiting in birds, or attempts at vomiting, the temperature comes back to its natural standard and soon begins to fall; and during the third and into the fourth degree the decline continues. In the fourth degree the temperature falls to its first minimum, and in birds comes down from five and a half to six degrees; in rabbits from two and a half to three degrees. In this condition the animal temperature often remains until there are signs of recovery, viz. conscious or semiconscious movements, upon which there may be a second fall of temperature of two or even three degrees in birds. In this course of recovery I have seen, for instance, the temperature of a pigeon which had a natural standard of 110° reduced to 102° . Usually with this depression of force there is desire for sleep, and with perfect rest in a warm air there is return of animal heat; but the return is very slow, the space of time required to bring back the natural heat being from three to four times longer than that which was required to reduce it to the minimum.

In these fluctuations of temperature the ordinary influences of the external air play an important part as regards duration of fluctuations, and to some extent as regards extremes of fluctuation.

The introduction of alcohol into the body in frequent and small quantities, so as not to produce any of the stages of true intoxication, is attended with a reduction of temperature limited to one and a half degree in small mammalia. The effect is definite on the administration, and occurs under varying circumstances—before food, after food, and in atmospheres of different warmth. It is most definite when the alcohol is administered by the hypodermic method.

When the alcoholic sleep from ethylic alcohol is pushed to the fullest extent, a very long time elapses after perfect unconsciousness is developed before the respiratory, circulatory, and even some of the voluntary muscles cease to act. The movement of the voluntary muscles is not, however, by an act of consciousness; it is not reflex, and it cannot be excited by the touch. It is usually an automatic movement, and will continue in the limbs for a long time. At last nothing remains to give evidence of the continuance of life except the motion of the heart and diaphragm, the persistency of the action of which is amongst the most curious facts in physiology. The final act rests with the heart; the heart continues to contract when the breathing has ceased, and is found contracting on the right side in both auricles and ventricles, on opening the body, when all the outward indications of motion are over.

I notice particularly that prolonged tremors do not seem to be produced by ethylic alcohol.

The appearances immediately after death from ethylic alcohol intoxication are very distinctive. The brain is found charged with fluid blood, the sinuses distended with exudation of serum in the ventricles and in the membranes. The small vessels of the brain are greatly injected. The lungs are white, free from congestion, and well inflated with air. The heart is full of blood on both sides, and its air-vessels are engorged. The liver is natural, and the gall-bladder is not distended. The inner surface of the stomach, even when the intoxication is induced by the gradual inhalation of the vapour or by subcutaneous injection, is very much congested, and a strong odour of the alcohol pervades any contents that may be within the stomach. The spleen is normal, and the alimentary tract below the stomach is normal. The kidneys are intensely congested, blood exuding freely from the cortical part, in points or specks. The bladder is usually empty. The blood on the left, as well as on the right side of the heart, is dark, but on exposure to air it soon reddens, and coagulation is firm. The corpuscles undergo great changes, even before death; they are shrunken, crenate, and some are elongated and flattened, with truncated ends.

BUTYLIC ALCOHOL.

Butylic alcohol, obtained by fractional distillation from fusel-oil, or from the oil of beet-root, or from molasses left after distillation of ethylic alcohol, differs, as our Table shows, from ethylic alcohol in the proportion of carbon and hydrogen. Compared with common alcohol, its vapour-density is as 37 to 23, its specific gravity is as .803 to .792, and its boiling-point is as 230° F. to 172°. It is a heavier alcohol: it mixes indifferently with water, but is not unpleasant to take when diluted and sweetened. Applied to the lips and tongue in the pure state, it burns more than ethylic alcohol, and it leaves a very peculiar and prolonged local numbness, not unlike the numbness left by tincture of aconite. The knowledge of this fact may prove of service in the application of the alcohol for the local relief of pain.

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regular intervals spontaneously: but they can be excited by a touch at any time, and in the intervals, when they are absent, there is frequent twitching of muscles. The tremors themselves are not positively muscular contractions, but are rather vibrations through the whole muscular system, and are connected with extreme want of true contractile power. While they are present the temperature declines, and a difference of a full half degree may be observed both before and after each paroxysm. When the tremors are once established, they may continue without further administration of alcohol for ten and twelve hours steadily; and so slowly do they decline, that I have seen them occurring in the pigeon thirty-six hours after the intoxication. They subside by remission of intensity and prolongation of interval of occurrence.

There cannot, I think, be a doubt that these tremors, produced in animals by the heavier alcohol, are identical with the tremors observed in the human subject during the alcoholic disease known as *delirium tremens*. What the nature of the muscular movement is, what unnatural relationships exist between the nervous system, the muscles, and the blood to cause them, these are questions of singular interest. Involuntary, developed even against the will, excited by any external touch that sets up prostration, attended with great reduction of temperature, and remaining so long as the temperature is low, they indicate clearly an intense depression of animal force, a condition in which all the force that remains seems to be expended on the organic acts of life, on the support of the motions of the heart, the muscles of respiration, and the functions of the secreting glands. The voluntary systems of nerve and muscle are indeed well nigh dead, and recovery rests entirely on the maintenance of the organic nervous power.

In the extreme stage of intoxication from butylic alcohol the arterial blood loses its red colour, and the blood, which flows with difficulty from veins, is of dirty hue. Coagulation occurs readily, but the clot is loose, and yields much coloured serum. The corpuscles are closely massed together in rolls, several appearing as if they made one distinct column. The fibrine separates in masses or bands, forming a coarse network or mesh very distinctive in character.

AMYLIC ALCOHOL.

I have already reported, at the Birmingham Meeting of the Association, on amylic alcohol. In its effects, as a reference to my Report will show, it differs only from butylic alcohol in that the symptoms are even more prolonged. The tremors are most persistent, and complete recovery, as indicated by restoration of the natural temperature, is not often attained in a shorter interval than three days. At the same time, owing probably to the comparative insolubility of this alcohol by the blood, it is very difficult to destroy life with it by simple gradual administration. When to the ordinary observer recovery seems impossible, when there is perfect insensibility, when there is perfect paralysis of voluntary muscle, when even tremors cannot be excited, and when the only evidence of life is a feeble respiration at intervals of many seconds, recovery may be made certain.

* REVIEW OF THE ALCOHOLS.

Reviewing the alcohols as a class, we find that their physiological action, less extended in regard to particular organs than the nitrates, and more extended than the insoluble hydrides, is expressed both on the organic and cerebro-spinal centres, reducing the active functions of both systems, and at last so reducing the function of the cerebral hemispheres as to remove con-

sciousness altogether. The leading peculiarity of the action is the slowness with which those centres which supply the heart and diaphragm with power are affected. In this lies the comparative safety of alcohol; acting evenly and slowly, the different systems of organs fall together, with the exception of the two on which the continuance of mere animal life depends. But for this every deeply intoxicated man would die.

The alcohols are strictly anæsthetics; and indeed the first published case of surgical operation under anæsthetic sleep was performed, in 1839, by Dr. Collier on a person who was rendered insensible by breathing the fumes of alcohol. But the anæsthesia is not commendable; it is too slow and too prolonged. Methyl alcohol, if it could be entirely purified and made inodorous, might be used, and with methyl ether it would be one of the safest of agents; but as yet its inhalation is disagreeable.

The difference of action of the alcohols, as they ascend in the series and as the carbon increases, is most striking. The slowness of action, the prolongation of action step by step, from the lighter to the heavier compounds, is a fact as definite as any in physiology. Curious is it also that neither the methyl nor the ethyl alcohols produce those tremors in the inferior animals which we recognize and specially name from their occurrence in man; while the butyl and the amyl most effectively call them forth. Considering how much of the heavier alcohols is distributed for consumption, especially among the lower orders, I think it is possible that the heavier fluids may also be the cause of *delirium tremens* in the human subject, as they are frequently the cause of that continued coldness, lassitude, and depression which follow the well-known dinner with "bad wine."

Speaking honestly, I cannot, by any argument yet presented to me, admit the alcohols through any gate that might distinguish them as separate from other chemical bodies. I can no more accept them as foods than I can chloroform, or ether, or methylal. That they produce a temporary excitement is true; but as their general action is quickly to reduce animal heat, I cannot see how they can supply animal force. I see clearly how they reduce animal power, and can show a reason for using them in order to stop physical or to stupify mental pain; but that they give strength, *i. e.* that they supply material for construction of fine tissue, or throw force into tissues supplied by other material, must be an error as solemn as it is widespread.

The true place of the alcohols is clear; they are agreeable temporary shrouds. The savage, with the mansions of his soul unfurnished, buries his restless energy under their shadow. The civilized man, overburdened with mental labour, or with engrossing care, seeks the same shade; but it is shade, after all, in which, in exact proportion as he seeks it, the seeker retires from perfect natural life. To search for force in alcohol is, to my mind, equivalent to the act of seeking for the sun in subterranean gloom until all is night.

As yet alcohol, the most commonly summoned of accredited remedies, has never been properly tested to meet human diseases. I mean by this, that it has never been tested as alcohol of a given chemical composition, of a given purity, and in given measures. Wines, beers, spirits, are mixtures—compounds of alcohols, and compounds of alcohols with ethers and other organic substances. It is time, therefore, now for the learned to be precise respecting alcohol, and for the learned to learn the positive meaning of one of their most potent instruments for good or for evil; whereupon I think they will place the alcohol series in the position I have placed it, even though their prejudices in regard to it are, even as mine are, by moderate habit and confessed inconsistency, in its favour.

THE CHLORIDES.

I have in previous Reports brought forward the properties of the chlorides of methyl and ethyl. The first is an admirable anæsthetic, when inhaled in the proportion of 15 per cent. : it ranks in safety next to methylic ether, and a compound made of it with absolute ethylic ether is perfect. The objection to it is that, being a gas, it is not easily manageable.

Chloride of ethyl stands in the same position as chloride of methyl ; but the action of it is much more prolonged, and a longer time is required for the production of action. With absolute ether it forms an excellent compound, the objection to which is, simply, its instability.

The chlorides of butyl and amyl have an action so much alike that they may be taken together ; both are simple and effective anæsthetics, and both are pleasant to inhale, the butyl chloride being most agreeable.

The peculiarity of their action is that the sleep they induce is extremely prolonged, this being specially the fact with chloride of amyl. Pigeons when put to sleep by breathing ten per cent. of chloride of amyl pass slowly through the three degrees of anæsthetic insensibility easily and without convulsion, but invariably with slight vomiting. From ten to twelve minutes of inhalation are required to produce perfect sleep, and the temperature of the body falls full four degrees. The sleep once produced will continue in the common air at 70° Fahr. for fifteen minutes profoundly. The awakening is quick, and recovery is perfect.

In rabbits the action is much the same ; seven minutes are required to produce safe narcotism, and the sleep produced is very profound. The breathing is tranquil, and the eyes, as is the case from amylene, usually remain open. A rabbit will lie five-and-thirty and even forty minutes in this state of insensibility before showing signs of recovery, and the temperature will fall from 3° to 4° Fahr. If the inhalation be carried too far, the profound sleep I have mentioned passes slowly into death, the sleep being prolonged in the common air at 70° Fahr. a full hour and a half prior to death. During this time the respiration for the most part is natural, with occasional double breathing ; but the temperature of the body is all the while gradually declining, and is even reduced, while yet the animal is breathing, to 21° Fahr. below its natural standard. Thus in one case the temperature of a rabbit fell from 103° Fahr. to 82° Fahr. This is the lowest reduction I have seen in connexion with symptoms of living action ; but from this extreme condition recovery is possible if the respiration be sustained in a warm air.

After death from the chloride of amyl the heart is found charged with blood on both sides, and the action of the auricles and ventricles is long persistent. The blood is very slow to coagulate ; but the venous and arterial bloods retain their colour. The lungs are natural. The blood-corpuscles are much changed ; they are shrunken, ~~so~~ to, and elongated, with truncated ends.

The brain is left bloodless and of the purest white.

NOTE ON THE CHLORIDES.

The whole of the substances in the chloride series are simple and pure anæsthetics, and the power of their action obviously increases in proportion as there is increase of carbon. They act most readily and determinately on the cerebrum, and on the centres of volition and common sensibility. They have little action on the organic nervous system, and they interfere, even in full doses, but very gradually with the movements of the heart and respiration. The chlorides

of butyl and amyl have yet to take a very important part in medicine; they admit of being applied in many cases where a prolonged sleep is required; for this purpose they may to a considerable extent replace opium.

THE IODIDES.

The action of the iodides of methyl and of amyl have already been reported on: they both produce insensibility; the first causing free elimination from glands, and the second causing tremors resembling those induced by amylic alcohol.

The iodide of ethyl resembles the methyl compound closely in its action, but it produces sleep more quickly and with less irritation. The vomiting produced by it is severe, and its action, if carried to the production of insensibility, is not comfortably safe. It may be administered either by inhalation with ether or by subcutaneous injection; it brings down temperature six degrees in birds. *The iodide of butyl* is very slow in its action, and produces symptoms closely resembling those caused by the amyl iodide, viz. tremors, and, during recovery from the insensibility, motions, partly voluntary, in a circle or semicircle, which continue for a long period. The temperature falls under the influence of this agent from five to six degrees in pigeons, and from two to three degrees in rabbits. The colour of the blood is much heightened, the venous appearing as arterial blood, and the coagulation is very slow. The corpuscles are not injured, and show no disposition to coalesce. Recovery from the insensibility produced by the butyl iodide is good. The iodide may be administered by inhalation with ether or methylic alcohol, or by subcutaneous injection; and it has this advantage, that of all the iodides it shows least disposition to undergo change on accidental exposure to the air.

NOTE ON THE IODIDES.

The substitution of the element iodine in the organic bodies, marked in our Table, induces evident difference of physiological action. The action of the iodine is throughout on glandular structure, an excitation of glandular action and elimination, the action declining as the quantity of iodine is reduced. The whole of these organic iodides exert an eliminatory as well as an anodyne influence, and for this reason they promise to be of great service in medicine. Iodide of butyl will probably be found to be the best of the series.

To make them applicable as internal remedies, I have studied carefully the best mode of preparing them, and find the form of syrup by far the most effective and convenient. Specimens of syrups are before the Section.

PART II.—MEANS OF RESTORATION.

The second and concluding part of my Report has reference to the all-important question of the best means of meeting what seem to be fatal accidents arising from the administration of those agents which are most commonly in use. In this direction of research I have had unexampled opportunities of study, and I regret only that the length of my Report necessitates an undue brevity on this one particular topic.

The substances which commonly produce dangerous symptoms divide themselves into two classes,—those which produce prolonged intoxication, and those which produce quick insensibility and immediate death. The alcohols are illustrations of the first of these series; the chlorides and ethers, and, indeed, all the very volatile and gaseous narcotics, are illustrations of the second.

Respecting the means of recovery from the intoxication by the slowly acting narcotics, the rules are extremely few and simple: they are two only, and they include all; they are (*a*) exposure of the animal to warm air, and (*b*) in extremity the steady and efficient maintenance of artificial respiration. When these rules are rigorously followed, death from the profoundest intoxication is rare. This remark applies even to those extreme examples where there are tremors of muscles and all the signs of instant dissolution. The temperature of the air should be, as a rule, about ten degrees below that of the natural temperature of the animal. But in intervals of great depression the temperature may be raised to ten and even twenty degrees above the degree of temperature natural to the animal.

In regard to recovery from the extreme and sudden effects of the second class of substances, moderate warmth of air is again an advantage; but sudden extreme warmth is often fatal, from the expansion of gaseous matter in the lungs. From 60° to 65° Fahr. is the best temperature for recovery from the more volatile agents.

In both classes of cases artificial respiration is often all essential; but it may be used to kill as well as to save, unless it always be used with a perfect knowledge of what it is to do.

And this I find to be a rule having no exception, that it is always bad practice to excite artificial respiration so long as there is anything like a natural respiration. If the subject be breathing once in ten or even fifteen seconds, it is best to let well alone. The reason for this rule is simple, and rests on the fact that the balance of circulatory and respiratory power must be sustained. In health there is a nicely adjusted balance of pressure between the blood brought by the action of the right side of the heart to the lungs to be aerated, and the air brought by the muscles of respiration to effect aëration. To resort to any violent means to enforce respiratory movement is to destroy this delicate balance, to cause rupture of the air-vesicle, and infiltration of air into the surrounding tissue—emphysema. In brief, when the current of blood passing from the right to the left side of the heart is reduced, as it is in the cases we are treating of, to the extreme of debility, the point of practice is to bring back the respiration and the circulation together. We must treat the body, in a word, as we would a candle or lamp, the active flame of which is extinguished, but the wick of which is still burning without flame. It is also important, in performing this act, not to disturb the body by any sudden movement, for the least motion, when the circulation is ebbing, is often sufficient to stop the enfeebled and hesitating heart.

To meet these refinements in the method of restoring animation, I have invented the simple pocket-bellows which I place before you; they are made of india-rubber, and the bellows part consists of two round balls, which can be grasped by one hand. When the bellows are compressed, the ball on the right-hand side yields the air it contains to the long exit-tube, while the ball on the left hand yields the air it contains directly to the outer atmosphere. When the bellows are allowed to fill with air, the right ball fills directly from the pure air, the left from the long exit-tube. When, then, the long exit-tube is inserted in the nostril, and the bellows are worked together, one bellows fills the lungs, during compression, with pure air, the other empties the lung, during expansion, of impure air. Thus the natural conditions for breathing are carefully imitated, and the manipulation is simple to the last degree. In using the bellows I commonly leave one nostril quite open, putting the tube of the bellows firmly into the other. Then I commence gentle inflation, and continue until such time as the action of

the heart has ceased, and all further attempts are useless, or until there is evidence of natural respiration. But when there is once evidence of natural respiration, I am specially cautious to do no more unless the natural act should of itself cease, when I repeat as before. In all my experiments I have never seen the respiration cease after it has been restored, except in one solitary case, and then the relapse was probably due to injury due to forcing the artificial respiration too strongly at first. On the other side I have frequently seen the continuance of artificial respiration, after the establishment of natural respiration, from the doing too much, destroy effectually the good which had previously been accomplished.

With this convenient instrument, after cessation of breathing by any of the narcotic vapours not heavier than chloroform, life seems to me to be restorable in a large majority of cases, if the respiration be artificially commenced within three minutes after its cessation.

CONCLUSION.

I have thus, Mr. President, brought my labours this year to a close. Had time been permitted for further research, I should have entered upon the study of one or two new series of bodies; but the labour must be held in reserve.

We cannot pretend in Reports like these to vie with our more fortunate brethren in other departments of science. The physiologist has no ground of pleasant work in common with the astronomer, the geographer, geologist, ethnologist, or chemist. His researches are hard (unrelenting I had almost said), excessively minute, laborious, and at all times, however absorbing, painful; many of them can, in fact, only be carried on under a sense of duty amounting to necessity, and with the sincerest, the most solemn feeling that they are being conducted for the ultimate benefit of all the higher classes of animal existence. In the preparation of this Report I have held on throughout by this sense of duty, and earnest faith that good must come out of the labour.

One object which I had directly in view has been to introduce certain new substances which may be directly applied in our treatment for the cure of disease, or for relief of pain; another object has been to discover the best means of removing danger, from the use or abuse of some of the more potent agents; but the leading idea of the Report is that which I brought forward at the Birmingham Meeting—the idea of studying the action of substances which are to become remedies, not by the old and faulty method of so-called experience, but by proving physiological action and the relation of chemical constitution to physiological action. I am certain the time must soon come when the books we call “Pharmacopœias” will be everywhere reconstructed on this basis of thought, and when the chemist and physician will become one and one. That this huge reform may be commenced by order of the legislative authorities in this country is to me an earnest hope. But whether this shall be the final result or not, I shall always recall, with satisfaction, the remembrance that the idea of the reform and the first working of it began in England, and under the auspices of the British Association for the Advancement of Science.

On the Influence of Form considered in relation to the Strength of Railway Axles and other portions of Machinery subjected to rapid alternations of Strain. By F. J. BRAMWELL, C.E.

[Plates III. & IV.]

BEFORE the days of railways, when not only was there much less machinery on which to found observations, but such machinery as there was worked under far lighter strains and with far fewer alternations of those strains in a given time than the machinery of the present day is subjected to, the question of the influence of form was not an obtrusive one; and, in fact, so long as the weakest part of any piece of machinery, such as a shaft, had the sectional area due to the efficient resistance of the strains that could be ascertained as coming upon it, little or no attention was paid to the manner in which this smallest sectional area was to be associated with enlargements formed for the purposes, in the case of shafts, of receiving wheels or of acting as collars.

As an instance of this, few engineers in the pre-railway days would have hesitated to make a cast-iron crank-shaft for a steam-engine in the manner shown in fig. 1, Plate III. They would have taken care to give the bearings (or journals as they are called) A A such a diameter as was judged to be sufficient, having regard to the area of the piston, the pressure, and the length of stroke; but they would have made the body part, B, of the shaft and the end, C, in the eye of the crank of a much larger section than that of the bearings A A, would probably have made these parts square, and would without hesitation have formed the junctions of the small parts A A with the large parts B and C abruptly with right angles, as drawn in full lines, and without any attempt to ease off the change in form by a bold curve, as shown by the dotted lines.

The square shoulder would be left, in order to get a good endway bearing against the sides of the supporting brass; and few, if any, engineers in those days would have imagined that if the bearings A A were large enough, the making the shaft at B and C of a greatly increased section, and the making the junctions of these sections with the sections A by right angles, could in any way be prejudicial to the strength of the bearings A A. The opinion was (and, on the face of it, by no means an unreasonable opinion) that if the bearings A A were strong enough, the fact of any neighbouring part being stronger could not in any way detract from the value of A A.

Occasionally, however, there were occurrences which might have aroused attention, but which, it is believed, were allowed to pass by, being accepted as mere workshop accidents, and not thought worthy of inquiry by the skilled engineer of the time; and still less were they treated as problems to be solved by scientific men outside the profession of engineering.

Fig. 2, Plate III., illustrates one of these occurrences. It shows a form of eccentric rod commonly then in use. In such a rod the ends A A were made of long screws to carry nuts to tighten against the lugs of the eccentric band, as shown dotted at B B; these ends (A A) were forged in short lengths, say, from C, and after having been turned at the parts A A and screwed, were welded at C to the body of the rod.

It was by no means a common thing, but occasionally it did happen, that, in the act of making the weld at C, the screwed end snapped off at D close to the enlarged part without any blow whatever having been struck upon the end. It has been said the occurrence was not a common one; but it was

Fig. 1.

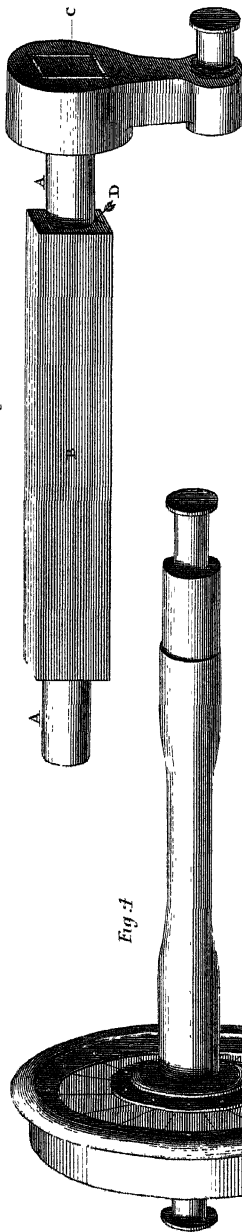


Fig. 2.

Fig. 3.

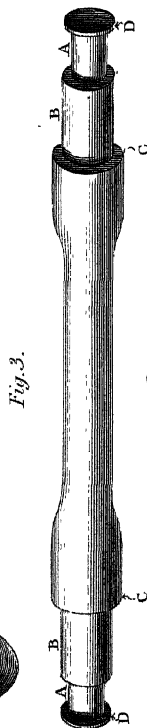


Fig. 3a.

Fig. 2.

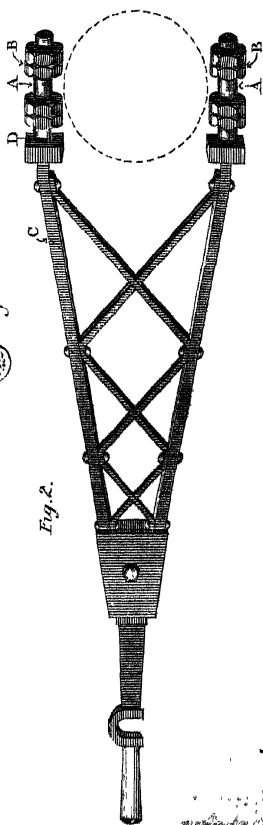


Fig. 6.

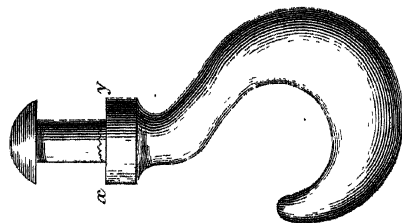
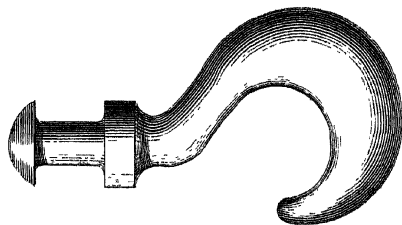


Fig. 5.



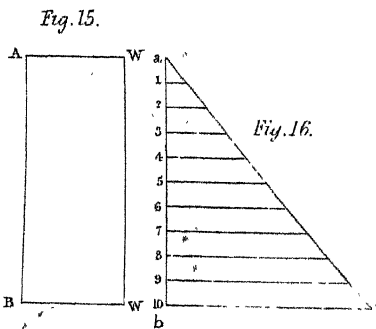
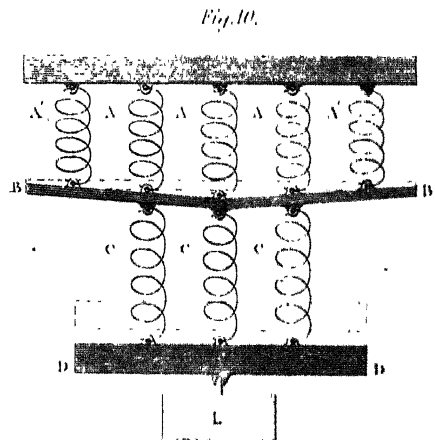
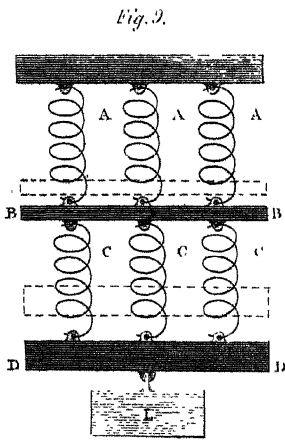
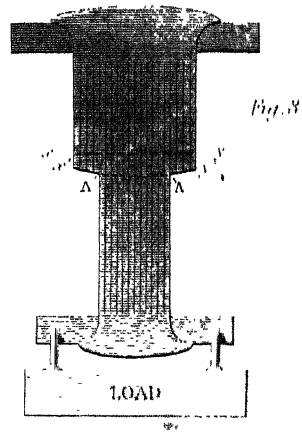
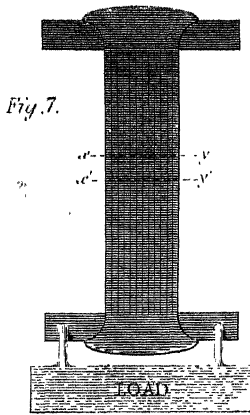
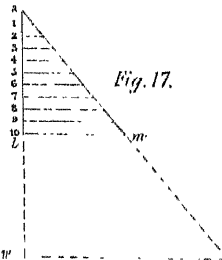


Fig. 16.



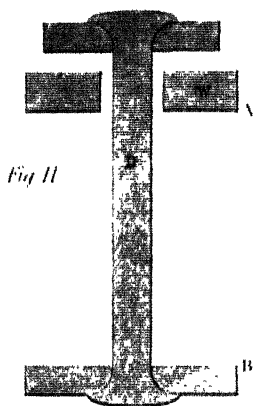


Fig. 11

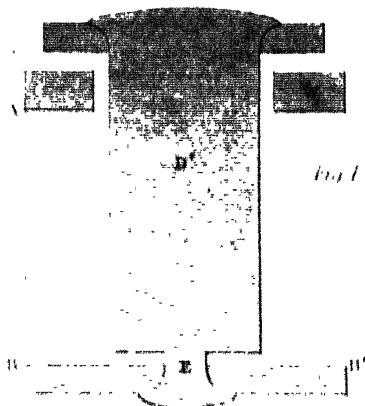


Fig. 12

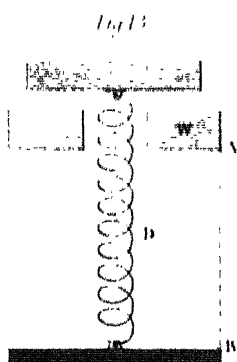


Fig. 13

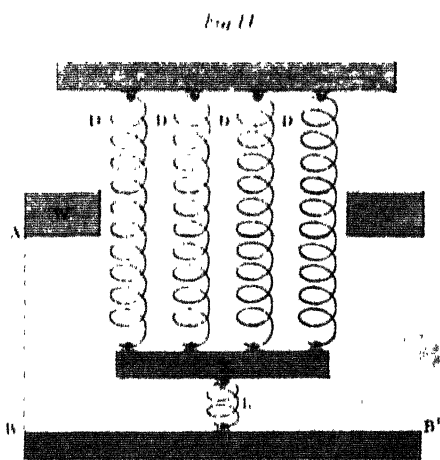
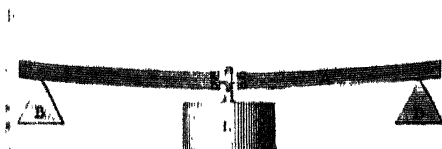


Fig. 14

Fig. 18.



Fig. 19.



suspended bar of uniform sectional area in its body part, and let fig. 8 represent another suspended bar of the same sectional area at its lower part as the bar of fig. 7, but having an increased section at its upper part, such increase being *abruptly* made; then, if these two bars be supposed to be subjected to equal loads, there will be more strain at the outside of the smaller part of the bar fig. 8, say at A A, than there is on any part of the uniformly small bar fig. 7.

Assume that the bars are composed of a number of equally elastic parallel columns (and to get rid of any question of what may be called the natural fibre of wrought iron not following the outline of bar fig. 8, let it be supposed that the bars are made of cast iron or cast steel); now if these elastic columns are capable within certain limits of equal increase of extension with equal increments of load, it follows that if the bar fig. 7, when unloaded, were to have a horizontal line drawn across it, as at xy , and the bar were then to be loaded, the result would be to lower this line to the position $x'y'$, the line still being horizontal.

In fig. 8, however, where the wide upper part contains a greater number of such elastic columns than its lower part (or than the bar of fig. 7 contains), then if the horizontal line were in the unloaded state of the bar drawn at xy (the part where the dimensions abruptly change), and if the load were afterwards applied, xy could not be drawn down so great a distance as in the case of the bar fig. 7, because there are more elastic columns on the upper part of the bar fig. 8 to uphold the load than there are in the bar fig. 7; and, moreover, xy could not be drawn down so as to preserve its straightness, unless it could be assumed that the elastic columns at the sides of the wide upper part were equally extended with those in the middle; but it is obvious that these outer upper elastic columns, not having any columns below to pull them, can only be brought down by their lateral connexion with the neighbouring upper elastic columns; but this connexion being in itself elastic, the effect can only be to draw the outer parts partially down, and thus to cause the lowered line xy to assume the curved form of $x'y'$. Now it will be seen that this curved form of the line $x'y'$ involves the outer elastic columns being more extended than the internal columns of the lower part of the bar; but as the strain on the elastic columns may be ascertained by referring to their extension, this proves that the strain is not uniformly distributed, as in the case of the bar fig. 7, and that the outer elastic columns of the lower part of the bar fig. 8 are more strained than the columns of fig. 7, and still more strained than the internal columns of fig. 8.

An endeavour will be made to explain and establish this proposition by the diagrams figs. 9 & 10. In these diagrams the cross bar B B is taken as the equivalent of the lateral connexion which exists among the elastic columns in the bars figs. 7 & 8.

Let fig. 9 represent three spiral springs, A A A, suspended at equal distances apart, and attached at the bottom to the bar B hinged in the middle, and let C C C be three other similar spiral springs attached at their upper ends to the bar B, and at their lower to a perfectly rigid bar D carrying the load L.

Under such an arrangement as this the load would be uniformly distributed, and the result would be simply to stretch the springs equally and to lower the parts B and D from their original positions indicated by the dotted lines. Now let it be assumed that, as in fig. 10, two other springs, each equal to one of the springs A, have been placed alongside of the first, and have been attached to the outer ends of the hinged bar B, and a load L has been applied to the bottom bar D as before; the result

of such a construction would be to pull down the hinged bar B, no longer in a manner to preserve its horizontality, but to bring it down in a bent form, and thereby to cause less of the load to be carried by the middle lower spring C than its fair share of one-third, as carried by the middle spring of fig. 9, and to throw of necessity this deficiency as an extra burthen upon the two outer springs C C.

The writer trusts he has succeeded in making his meaning clear, and has proved his proposition that, even under a quiescent load, a sudden increase of dimension in a suspended bar carrying such a load is a source of weakness. If the writer has not succeeded in making his meaning clear, he is at a loss how to illustrate it further, unless it be by some such proposition as this. Assume 100 men opposed in line to 100 men also in line, then the conflict would be equal for all; and then assume that one of the contending parties is increased to 102 men by placing one man on each flank; the two men will clearly exert but little influence upon those who are fighting in the centre of the lines, but their presence will be most injuriously felt by the two flank men of their opponents, as these two men will each have to contend with two adversaries in lieu of one. In the same way the internal elastic columns in the lower part of the bar fig. 8 have only similar fibres to deal with up above; but the external fibres of the lower part have not only to deal with their own proper continuations above, but have also to deal with the fibres above them in the parts projecting at the sides.

The second proposition comes now to be considered, namely, the influence of the abrupt change of form when the force of impact has to be resisted by the elasticity of an assumed imponderable bar.

Let D, fig. 11, be a plain bar of uniform section in its body part, but with an enlargement at the top to enable it to be suspended, and with one at the bottom to receive a collar, B, on which the weight, W, is supposed to fall through the distance A B.

The bar D', fig. 12, is assumed to have in its body part four times the sectional area of D, but to terminate at its bottom end in a short piece E, having a sectional area equal to D, or one quarter that of the upper part, D'. This bar, D', is also provided with a weight, W, falling through A B on to the collar B'.

Now let the spring arrangements of figs. 13 & 14 be substituted for the bars D and D'.

In fig. 13 there is a single spring D suspended from a support, and carrying a collar B on which the weight W can strike on falling through the distance A B.

In fig. 14 there are four suspended springs, D' D' D' D', each equal to D of fig. 13. These springs are supposed to be united at their lower ends to an absolutely inflexible bar X, below which is a short single spring E, similar in area and strength, so far as it goes, to either of the springs D, D'.

This spring, E, supports the collar B', to be struck by the weight W on falling through the distance A B equal to the A B of fig. 13.

Now if, as in any of these figs. 11 to 14, the weight W be suffered to fall through the distance A B, the accumulated work residing in it when it reaches B will equal the weight into the distance.

Let this accumulated work be represented by the parallelogram (fig. 15) A B W W.

This accumulated work it is intended, in the case of fig. 13, to transfer to the spring D, by the extension of that spring; but as the resistance by the spring will increase directly as the extension of it, the eff

spring to receive accumulated work may be represented by the triangle fig. 16, where ab represents the extension, and the several horizontal lines represent the strains due to the different extensions, the strains increasing from 0 at " a " to bw ; and in order that the accumulated work represented by the parallelogram ABW may be transferred to the spring, its extension must be such that the area of the triangle abw shall equal that of the parallelogram ABW . The maximum strain brought on the spring under these circumstances will clearly be no more than that represented by the length of the horizontal line bw .

Now assume that the area of ABW has to be transferred to the four springs D' of fig. 14, it is clear that only one-fourth of the area will have to be borne by each spring, and the triangle representing the extension and strain of each of the springs will only have one-fourth of the area of that of abw .

Let fig. 17 represent such a triangle, then, in order that its area may be one-fourth, it follows that its sides must each be half of those of the triangle abw , that is, the length of al , the extension, will be half of ab , and the length of lm , the final strain, will be half that of bw ; but if this be true of each of the springs D' , the aggregate strain on the four springs must be double that of the strain on D .

But this double strain has, in the case of fig. 14, to be put on to the four springs D' by means of the short single spring E , therefore this spring, which is equal to D , will be put to a strain twice as much as that put upon D .

It may be well to remark, in passing, that the fact of the ultimate strains put on in arresting the accumulated work being double in the case of fig. 14 to those of fig. 13, although the weight is the same in both cases, is by no means inconsistent with the fact that when the springs are settled to rest and are supporting W as a quiescent load, the sum of the strains of the four springs D' must exactly equal that of the single spring D .

It has not been thought necessary to take into account the small increase in the fall of the weight W , due to the lowering of the collars $B B'$ on the extension of the springs.

There now comes to be considered the third proposition, that change of form produces increased strain under impact, when the weight and inertia of the object suffering the impact are taken into account.

It is quite certain that in practice, where a falling weight is arrested by a collar B or B' , the accumulated work of that weight would be partly taken up by the elasticity of the bar D or D' , and would be partly taken up by the setting of the particles of the bar itself into motion, such motion being greatest at the bottom of the bar, and diminishing in the higher parts, until at the top of the bar it would become nothing.

Reverting to figs. 13, 14, 16, & 17, let it be assumed, for the sake of simplicity, and as an illustration only, that all the weight of the apparatus resides in the collars $B B'$, and that the collar B' of the four-spring arrangement, fig. 14, is four times as heavy as the collar B of the single-spring arrangement, fig. 13.

Further, reverting to fig. 16, the weight W would be brought to rest in the time during which it would traverse with a decreasing velocity the height ab , and in fig. 17 the weight would be brought to rest in the height al , half of that of ab ; and the time to bring the weight W to rest in this latter case of fig. 17 would be half that required to bring it to rest in fig. 16.

Following this out, if the lines ab, al be divided into the same number of parts, say ten each, then the time to travel over part 1 in fig. 17

must be half that required to travel over part 1 in fig. 16, and the length of part 1 in fig. 17 must be half that of part 1 in fig. 16.

But the respective collars (BB') must have their weights put into motion with these velocities, so that the weight B' has to move through half of the space that B has to move through, and has to do it in half the time; but to move a weight through half the space that another weight is moved through, and in half the time occupied by that other weight, requires double the pressure; therefore it would take double the pressure to move B' that it would to move B, even if B and B' were equal in weight; but B' is four times the weight of B, therefore it will take eight times the pressure to move B' that it will take to move B, and in this case also the eight times the strain has to be put on by the single spring E, which thus gets eight times as much strain as the spring D.

The fourth proposition has now to be considered, namely, that abrupt change of form is a cause of weakness when vibratory action has to be endured.

As already stated, this cause is the one that has been most recognized by those who have touched upon the question.

The writer will not pretend to investigate what the value of this source of weakness is, as no means suggest themselves to his mind for doing so; it may, however, fairly be assumed that the times of vibration in the large section part of the bar will be different from those in the small, and that at a point where the change of shape occurs there must be a discord in the vibrations, and that thus the metal in this part must be exposed to strains which would not occur were the vibrations on the two sides this point synchronous.

Propositions 2 and 3 have been dealt with as though the increased strains brought upon the small sections by their neighbourhood to the large sections were uniformly distributed over the small sections, which have, for simplicity sake, been assumed to be composed of single springs.

But had these small sections been dealt with as being in themselves composed of several smaller springs, as was done in considering the cases of figs. 9 and 10, then it would have been found that the outer parts of those small sections were doing more than their share of the increased work, and therefore the evils arising from increased section, which have been treated of in propositions 2 and 3, must be multiplied by the evils due to the abrupt change of form considered in proposition 1.

The kind of fracture shown in end view in Plate III. fig. 3 *a*, namely, a fracture which begins all round about the outside and gradually penetrates, is an abundant practical proof that not only are strains arising from impact increased on part of a small section by the neighbourhood of larger sections abruptly joining on to the smaller ones, but that the increase is borne in an undue proportion (as was shown in the case of quiescent weights) by the outer particles of the small section at the part where they abruptly join on to the larger section.

So far this paper has dealt with the evil influence of sudden change of form when it is to be found in a suspended rod or in other positions where the influences act in the direction of the length of the object under consideration. In practice, the bolts which hold on armour-plating are instances to which the foregoing considerations are applicable, as such bolts receive in the direction of their length the quiescent strain, and also that arising from impact of the recoil of the armour-plating after it has been struck by the

It may be well to allude to the fact that Major Palliser has

the difficulty of the fracturing that took place in the ordinary bolts immediately at the junction of the screw parts with the shank, by diminishing the area of the shank, so as to be equal to that at the bottom of the thread, and has thus given in his armour-plate bolts a practical instance that the strength of parts may be added to by reducing that of their larger neighbours.

Besides the armour-plating bolts and other bolts, there are no doubt many cases in which both quiescent strain and the strain of impact are exerted in the direction of the length of the object; but there are probably a still larger number of cases in which the strains are applied transversely, and among them are the important instances of railway axles.

It may be well therefore to glance briefly at the influences exercised by a sudden alteration of form when that alteration occurs in an object exposed to transverse strain.

Let fig. 18 represent an elastic bar (A) of uniform section, placed on supports B B, and subjected to the action of the quiescent load L, the result will be simply to deflect it as sketched.

In this deflection the central parts may be assumed to be extended on the underside, and compressed on the upper, as represented by the converging space $abcd$.

If, now, the depth of the bar be abruptly increased in the part that lies between these lines $abcd$ and the two ends, as shown in fig. 19, the result will be to aggravate the strains at the parts $abcd$ in a similar way to that which was pointed out in respect of a perpendicularly suspended bar under a quiescent load. But if the bars have to resist impact, then a more serious difference, to the disadvantage of the bar with unequal sections, will be found. It is well known that if one bar be double the depth of another, the first bar will, under a quiescent load, deflect only one-eighth part of that which the second would deflect, the deflections being inversely as the cubes of the depths.

With respect, however, to the resistance offered to the flexure of the bars under impact and not under quiescent loads, the writer believes it can be shown that if there be two elastic imponderable bars alike in all respects except their depth, and if they be exposed within their elastic limits to the impact of equal forces, the result will be that, if the one bar be taken as unity in depth and as deflecting unity under the force, the other bar, having

a depth of n , will deflect according to the formula $\frac{1}{n} \sqrt{\frac{1}{n}}$.

Applying this formula to the case of a weight let fall upon a bar which is double the depth of another, the deflection of this bar of double depth will

only be $\frac{1}{2} \sqrt{\frac{1}{2}}$, or about .35 of that which it would have been if of the single depth; but to produce this .35 of deflection, the strain on the whole section of the bar of the double depth will be 2.828 times as great as it would be upon the bar of single depth.

So that if the bars (figs. 18 and 19) be exposed to the impact of similar forces, the bar fig. 18 would deflect through a space of 2.828 with a strain of .35 on the central parts, while before the bar fig. 19 could, so far as the greater part of it (namely its enlarged ends) is concerned, be deflected through a space of one, there must be put upon the middle section of it, not only in area, a strain of 2.828. As in the case of the vertical extra strain would be aggravated by the fact that it would not

be uniformly distributed over the area of one, but would be borne in a larger proportion by the outside particles, where they join the increased section.

It will not be necessary to go into the reconsideration, in respect of transverse strains, of the effects of inertia and vibration, which have already been touched on when considering direct strains; but it will be sufficient to say that the strains brought upon railway axles are of a very severe character, and that they are undoubtedly exaggerated by the large difference of dimensions of the neighbouring parts, and that nothing but the greatest circumspection in the designing and manufacture of these parts can insure safety to railway passengers.

On the Penetration of Armour-plates with long Shells of large capacity fired obliquely. By SIR JOSEPH WHITWORTH, Bart., C.E., F.R.S., LL.D., D.C.L.

At the Meeting of the British Association at Norwich, I contributed a paper to the Mechanical Section "On the Proper Form of Projectiles for Penetration through Water." This paper was illustrated by diagrams, showing the effect produced on an iron plate, immersed in a tank of water, by projectiles with flat, hemispherical, and pointed heads. Copies of those diagrams are now before you. In that paper I claimed for the flat-pointed form of projectile, made of any metal, three points of superiority over the ogival-pointed projectiles adopted in the service:—(1) Its power of penetrating armour-plates, even when striking at extreme angles; (2) its large internal capacity for bursting charges when constructed as a shell; (3) its capability of passing undeflected through water, and of penetrating iron armour below the water line. This latter feature was, I think, satisfactorily proved by the experiments described last year; and I desire to draw the attention of the Section to the experiments I have made for illustrating the penetrative power of long projectiles with the flat front, fired at extreme angles against iron plates.

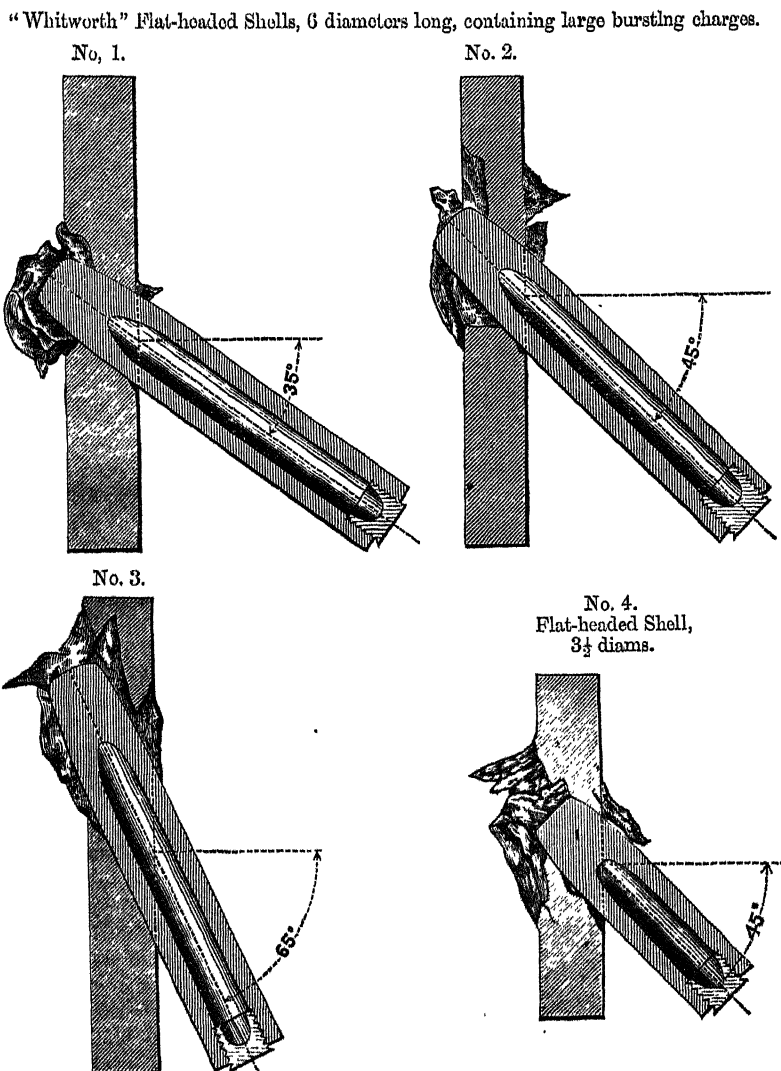
These experiments are illustrated by the projectiles actually fired, and the plates they penetrated, which are laid on the table, and also by the diagrams before you.

The gun from which the projectiles were fired is called a 3-pounder, though capable of firing much heavier projectiles. It weighs 315 lbs., and the maximum diameter of its bore is 1.85 inch. The charge of powder used, in all cases, was 10 ounces, and the weight of the 6-diameter projectile is 6 lbs.

No. 1 is a portion of a plate 2 inches thick, penetrated by the 6-diameter flat-fronted projectile No. 1 at an angle of 35 degrees. No. 2 is a similar piece of plate, 1.7 inch thick, completely traversed at an angle of 45 degrees by the flat-fronted projectile No. 2, which buried itself to a depth of 30 inches in a backing of iron borings. No. 3 is a piece of plate 1.75 inch thick, penetrated at an angle of 65 degrees by the flat-pointed projectile No. 3. No. 4 is a plate 1.7 inch thick, nearly penetrated, at an angle of 45 degrees by the 3½-diameter flat-fronted projectile No. 4. No. 5 is a plate 1½ inch thick, against which the ogival-pointed projectile No. 5 was fired at angle of 45 degrees; the projectile failed to penetrate the plate, being deflected in consequence of the pointed form of the head. The distortion of its shape at the force with which it struck the plate, and proves the good quality of the material which could resist such a test. No. 6 is a plate also 1½

against which an ogival-pointed projectile, of the service proportions, viz. $2\frac{1}{4}$ diameters long, made of Pontypool white iron, has been fired: the projectile has scooped out a furrow 4 inches long and seven-tenths of an inch deep; it broke up into fragments, of which 48 were recovered.

The plates Nos. 1 and 3 were purposely thicker than the projectiles could

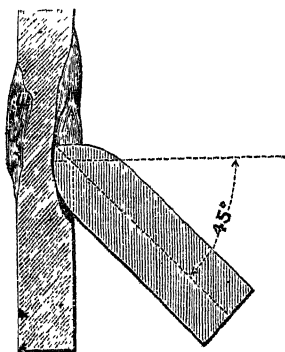


Nos. 1, 2, 3, and 4 were made of "Whitworth" Metal.

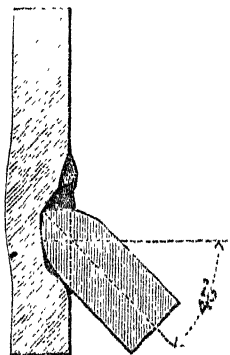
equite pass through, in order that the "work" of the projectiles might be as
ere as possible: an examination of the projectiles themselves will show
well they have withstood the severe strain to which they have been
The data thus obtained fully establish, I think, the superiority I

claimed for the flat-fronted projectiles made of my metal, and satisfactorily prove:—(1) That the flat-fronted form is capable of piercing armour-plates at extreme angles; (2) that the quality of the material of the shells enables

No. 5.
Pointed Solid Shot,
 $3\frac{1}{2}$ diams.



No. 6.
Pointed Solid Shot,
 $2\frac{1}{2}$ diams.



No. 5 was made of "Whitworth" Metal; No. 6 of Pontypool White Iron.

their length to be increased, without any risk of their breaking up on impact, and materially augments their bursting-charge as shells; (3) that this increase in length, while adding to the efficiency of the projectile as a shell, in no way diminishes, but, on the contrary, proportionally improves its penetrative power; (4) that the amount of rotation I have adopted in my system of rifling is sufficient to ensure the long projectiles striking "end on," and consequently to accumulate the whole effect of the mass on the reduced area of the flat front.

These experiments show, further, that the ogival-pointed projectile has but small power of penetration when striking at an angle, solely on account of the form of the head; a projectile of "Whitworth" metal, with the like ogival-pointed head, as a service projectile, having resisted the shock of impact without breaking up, but being deflected in precisely the same manner as the pointed service projectile, which was shattered into fragments. The objections I made in my paper last year to the ogival-pointed projectile—(1) that its form of head causes it to glance off from plane or convex surfaces when hitting diagonally; and (2) that the brittleness of its material renders it liable to break up on impact—I have now proved to the Section. The facts illustrated by these experiments are not of recent discovery. Ever since 1858 I have constantly been advocating the flat front. I have on the table a small plate $\frac{1}{2}$ inch thick, experimented upon in 1862 with hardened steel bullets fired from my small-bore rifle. No. 39 is the hole made by a flat-fronted bullet, which has penetrated the plate at an angle of 45 degrees. No. 40 is the indent of a hemispherical-headed, and No. 41 of an ordinary round-nosed bullet, both fired at the same angle of 45 degrees. These three rounds were fired in 1862.

Within the last few days I have had an ogival-pointed shaped bullet fired at the same plate at the same angle, in order to confirm the effect with that produced, on a larger scale, on the plate No. 6. It is interesting to observe how closely the results obtained with the small calibre of my rifle agree with those of the 3-pounder gun, which form the subject of this paper. Those experiments

recorded in the paper were made with a gun of smaller calibre, from considerations of economy and convenience; but I have always found that what I could do with the smaller calibres of my system, could be reproduced in the larger sizes; and from my past experience I feel warranted in asserting that the effect of penetration now exhibited could be repeated on a proportionate scale with my 9-inch guns at Shoeburyness, or with the 11-inch guns my firm are now engaged in constructing.

A glance at the formidable nature of the projectiles thrown by these guns, and a consideration of the effects they may be expected to produce, will show the importance attaching to the question of penetration of plates by long projectiles. The 9-inch guns to which I have referred weigh 15 tons each, and are capable of firing powder charges of 50 lbs. A 9-inch armour shell, 5 diameters long, weighs 535 lbs., and will contain a bursting-charge of 25 lbs.

I have no hesitation in saying that these projectiles would pierce the side of a ship, plated with heavy armour, at a distance of 2000 yards, and at some depth below the water-line. The 11-inch guns will weigh 27 tons, and will be capable of firing 90 lb. powder-charges. The 11-inch shells, 5 diameters long, will weigh 965 lbs., and will contain bursting-charges of 45 lbs., and would pierce the side of the ship 'Hercules,' plated with 9-inch armour, at a distance of 2000 yards.

Were it not that the increased destructiveness of war must tend to shorten its duration and diminish its frequency (thus saving human life) the invention of such projectiles could hardly be justified; but believing in the really pacific influences of the most powerful means of defence, I call these long projectiles the "anti-war" shell. The principle I have always insisted upon, and laid down for my own guidance in artillery experiments (when either a low trajectory or penetration is required), is, "that every gun should be in strength capable of withstanding the largest charge of powder that can be profitably consumed in its bore." I have drawn up the accompanying Table of the sizes of the bores of my guns, with their proportionate powder-charges, and the guns will all be fully equal to this duty, and I believe the greatest possible effect from the consumption of a given quantity of powder will be obtained. But the guns adopted in our naval service are not equal to such a test; nor, as I believe, are they so proportioned as to realize the best effect from the quantity of powder they consume.

Four guns of 12-inches bore have lately been put on board the 'Monarch.' They weigh 25 tons each, and charges of 50 lbs. and 67 lbs. have been fired from them with projectiles of 600 lbs. weight. I have no doubt that these guns have been made with all possible care, and are as strong as their material and construction admits; but if the weight of these guns was in proportion to the capacity of their bore, and if the material were the best that our metallurgical skill could supply for such a purpose, they ought to fire 117 lbs. of powder, and projectiles of 1250 lbs. weight. They would then be efficient weapons; but at present they are more formidable in name than in reality.

We are often flattered by being told that we have the best guns in the world. That may or may not be the case. But I think that we should not best contented while we are still so far from having attained as much as our present advancement in mechanical and metallurgical science has rendered possible for us.

Particulars of Ammunition for Whitworth Guns, from 5·5-in. to 13-in. bore.

Calibre of bore.	Powder charge.	Common Shells, cast iron, 3·5 diameters long.		Armour Shells, Whitworth metal.			
		Bursting-charge.	Weight of shell.	3·5 diameters long.		5 diameters long.	
				Bursting-charge.	Weight of shell.	Bursting-charge.	Weight of shell.
in.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5·5	11·0	4·0	70	3·5	84·0	6·0	120
7·0	23·0	8·5	150	7·5	180·0	12·0	255
8·0	34·0	13·0	220	10·5	265·0	18·0	375
9·0	50·0	18·0	320	15·0	380·0	25·0	535
10·0	70·0	24·0	440	21·0	525·0	35·0	740
11·0	90·0	32·0	580	28·0	680·0	45·0	965
12·0	117·0	40·0	750	36·0	886·0	58·0	1250
13·0	150·0	51·0	960	47·4	1045·0	75·0	1615

Mr. Whitworth's patent cartridge increases the range from 15 to 20 per cent.

Report of the Committee on Standards of Electrical Resistance.

[Plate VI.]

The Committee consists of Professor Williamson, Professor Sir C. Wheatstone, Professor Sir W. Thomson, Professor W. A. Miller, Dr. A. Matthiessen, Mr. Fleeming Jenkin, Sir Charles Bright, Professor Maxwell, Mr. C. W. Siemens, Mr. Balfour Stewart, Mr. C. F. Varley, Professor G. C. Foster, Mr. Latimer Clark, Mr. D. Forbes, Mr. Charles Hockin, and Dr. Joule.

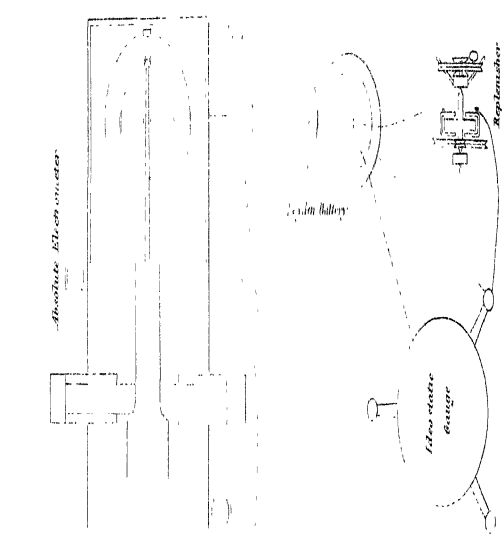
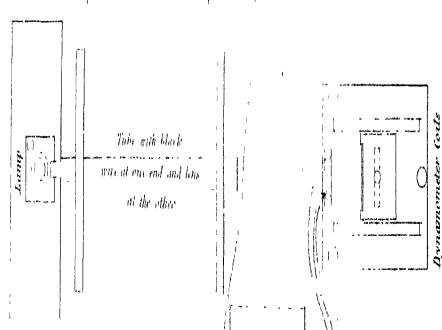
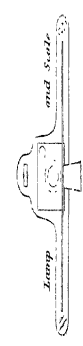
THE Electrical Standard Committee have this year had comparatively few meetings, and the results of the experiments made by the individual Members do not call for a Report of any length. It is, however, thought desirable to print at once, as Appendices, the important results obtained by Professor Clerk Maxwell, in determining the ratio of the electromagnetic and electrostatic series of units, and also a description of Sir Wm. Thomson's experiments on the same subject.

Description of Sir Wm. Thomson's Experiments made for the Determination of γ , the Number of Electrostatic Units in the Electromagnetic Unit. By W. F. KING.

The two principal pieces of apparatus used in these experiments were the absolute electrometer and the electro-dynamometer. The former of these instruments was described at the last Meeting of the Association, and a description of it is printed in the Report. The annexed Plate illustrates the arrangements described in what follows.

The electro-dynamometer consists of two large coils of fine copper wire, and a smaller coil of still finer wire. The two large coils are about 30 centim. diameter, and are placed vertical, in planes parallel to one another. The distance between the large coils is 15 centims. (equal to their radius). A smaller coil is suspended between the large coils by a copper wire of

Dr. Scale



At Home 12.50

Electrometer

At Home 12.50

thickness as to give the coil a time of vibration such that it completes a period in about thirteen seconds. The upper end of the suspending wire is attached to a milled head, and this head can be turned round by the fingers. The lower end of the wire is firmly fixed to the coil, and is in metallic connexion with one end of it. To the other end of the coil is soldered a spiral of very fine platinum wire which hangs directly below the coil, and its lower end is cemented to the dry woodwork of the instrument. To the fixed end of the spiral coil a copper wire is attached, whose other end is soldered to a binding-screw in an accessible position.

On one side of the small or moveable coil is fixed a plane mirror, and in front of the mirror, at a distance of about 450 centims., the scale is fixed on which the observations are read. A paraffin-lamp wire, to give dark line in image of flame, and lens are used in the ordinary way for finding accurately the angle through which the coil turns. It is never greater than $\cdot 05$. Its true amount can be determined to within $\frac{1}{10}$ per cent.

The connexions are not very intricate, and are traced thus:—Starting from one pole of the battery (the battery used was sixty sawdust Daniell's in series), the current goes in at one end of large coil No. 1, and from the other end of No. 1 the current goes to either end of the moveable coil, and the end of the moveable coil at which we suppose the current to be coming out is connected with the end of No. 2 large coil, similar to the end of No. 1, to which the battery was first attached, that is to say, the end which will make the current go round in the same direction in both the large coils. When the current leaves the extreme end of No. 2, it passes through a 10,000 B.A. resistance-box; the current is completed by connecting the other end of the resistance-box with the pole of the battery not already engaged.

The absolute electrometer is used in the ordinary way for measuring differences of potential, and its electrodes are connected, one to the end of the dynamometer coil No. 1, which is joined to the battery, and the other electrode is fixed to the end of the resistance-box, which is connected to the other pole of the battery. Thus the greatest difference of potential in the arrangement is measured by the absolute electrometer. An electrometer key is used to reverse these connexions in the course of the experiments.

There is only one other part of the arrangement to be explained, and that is the method of observing the resistance of the dynamometer coils while the experiments are going on. This was done by means of the resistance-box in the circuit and an electrometer. At one time the standard electrometer was used for this purpose, but more lately the quadrant, rendered unsensitive, was employed. Both these instruments are described in the last Report.

To take the resistance of the coils, the electrodes of the electrometer were first placed on the extreme ends of the three coils, and the difference of potential was ascertained. The electrodes were then shifted to the ends of the resistance-box, and the difference of potentials of its two ends was found. This gives at once the resistance of the coils.

There are two things which have to be done before the experiments are commenced. One is the determination of the moment of inertia of the moveable coil. This is done at the beginning and end of a long series of experiments, by comparing it with a ring whose moment of inertia is known. The other is done every day, and it is finding the time of vibration of the small coil after all the connexions have been made, and the coil put into its place. This was done both with the current from the battery flowing through the coils and with no current flowing; but this variation was of little consequence, as no difference could be detected in the time. When

the dynamometer is set up, care is taken to neutralize the effects of the earth's magnetism by a large number of magnets fixed at a great distance from the coils. If the adjustment of the magnets is perfect, there is no alteration of the position of the spot of light when the current is reversed through the coils by the battery-key. Up to the present time (May 1868) various causes have prevented the obtaining of as satisfactory results as the method described above allows us to expect. Eleven sets of experiments, made at various dates, from March 10 to May 8 of the present year, have indicated values for v , of which the greatest was 292×10^8 , the smallest 275.4×10^8 , and the mean 282.5×10^8 centimetres per second. Sir W. Thomson intends to continue the investigation, hoping to attain much greater accuracy.

[P.S. Nov. 1869.—A new form of absolute electrometer has now been completed and brought into use, with good promise as to accuracy and convenience. A glass jar constituting the "Leyden battery" contains within it the "absolute electrometer" proper, the "idiostatic gauge," and the "replenisher." One observer can use it effectively; although it is more easily worked by two, one maintaining constant potential in the Leyden jar by aid of the idiostatic gauge and the replenisher, and the other attending to the absolute electrometer (main balance and micrometer screw). The main balance, giving electric weighing in known weights, is as steady and as easily used as any of the "attracted disk" electrometers, whether portable or stationary, described in previous Reports.]

ERRATA IN PLATE VI.

For Dy Scale read Dynamometer Scale.

" Ideostatic read Idiostatic.

Add a connexion between outside of Leyden battery and one terminal of the neighbouring Electrometer key.

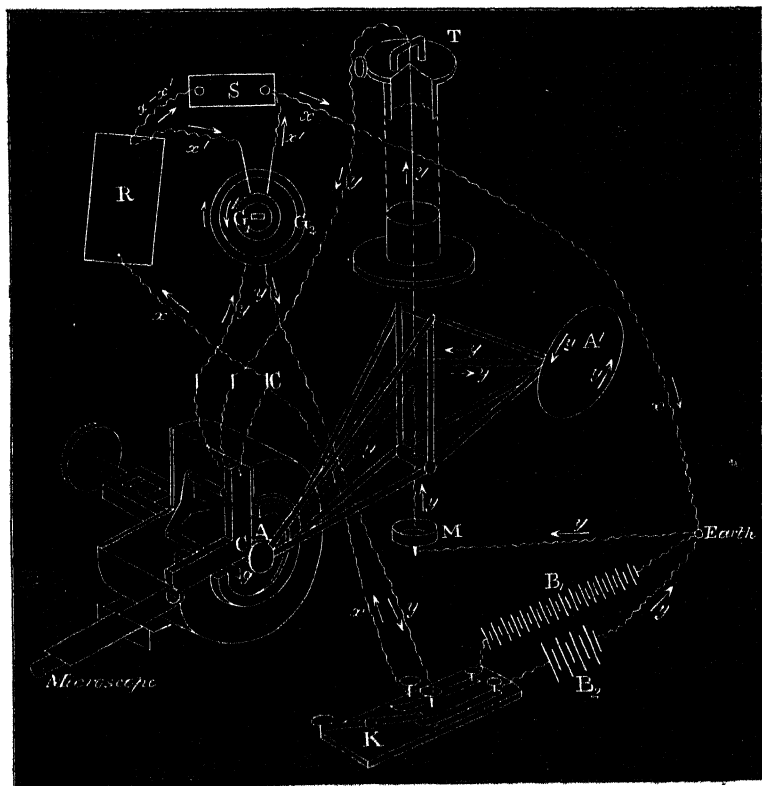
Experiments on the Value of v , the Ratio of the Electromagnetic to the Electrostatic Unit of Electricity. By J. CLERK MAXWELL.

The experiments consisted in observing the equilibrium between the electrostatic attraction of two disks, at a certain difference of potential, and the electromagnetic repulsion of two coils traversed by a certain current. For this purpose one of the disks, with one of the coils at its back, was attached to one arm of a torsion-balance, while the other, with the other coil at its back, was capable of being moved to various distances from the suspended disk by a micrometer screw. Another coil, traversed by the same current in the opposite direction, was attached to the other arm of the torsion-balance, so as to do away with the effect of terrestrial magnetism.

The fixed disk was larger than the suspended disk, and the latter, when in its zero position, had its surface in the same plane as that of a "guard-ring," as in Sir W. Thomson's electrometers. Its position and motion were observed by means of a microscope, directed to a graduated glass scale, connected with the disk. When the microscope was adjusted so that the image of the zero line on the glass scale coincided with the cross wires of the microscope, the very smallest motion of the scale could be easily detected, so that the observations were very rapid. The disk was brought to zero by the tangent screw at the top of the suspension-wire, and its equilibrium was always observed at zero. The equilibrium, when the electrical forces were applied, was always unstable. This electrical balance was made by

Becker. The experiments were made in the laboratory of Mr. Gassiot, who kindly gave the use of his great battery for the purpose. Mr. Willoughby Smith lent his resistance-coils, of 1,102,000 Ohms, Messrs. Forde and Fleeming Jenkin lent a galvanometer, a resistance-box, a bridge and a key, and Mr. C. Hockin undertook the observation of the galvanometer, and the testing of the galvanometer, the resistances, and the micrometer-screw.

The difference of potentials of the disks was compared with the current in the coils as follows:—One electrode of the great battery was connected to the fixed disk, and the other to the case of the instrument and the guard-ring



- A. Suspended disk and coil.
 A'. Counterpoise disk and coil.
 C. Fixed disk and coil.
 B₁. Great battery. B₂. Small battery.
 G₁. Primary coil of galvanometer.
 G₂. Secondary coil.
 R. Great resistance. S. Shunt.
 K. Double key. g. Graduated glass scale.

- C. Electrode of fixed disk.
 x. Current through R.
 x'. Current through G₁. $x = x'$. Current through S.
 y. Current through the three coils and G₂.
 M. Mercury cup. T. Torsion head and tangent screw.

One quarter of the micrometer box, disks, and coils is cut away to show the interior. The case of the instrument is not shown. The galvanometer and shunts were 10 feet from the electric balance.

and the suspended disk. They were also connected through the great resistance R, and the primary coil of the galvanometer G₁ shunted with a resistance S.

A small Grove's battery was employed to send a current through the three coils and the secondary coil of the galvanometer G_2 .

Equilibrium of the electric balance was obtained by working the micrometer, and so adjusting the distance of the disks. At the same time equilibrium of the galvanometer was obtained by altering the resistance of the shunt S .

The simultaneous values of the micrometer and the shunt formed the result of each experiment. It was necessary also to ascertain the ratio of the magnetic effects of the two coils of the galvanometer immediately after each set of experiments.

The method of experimenting appeared capable of considerable accuracy; but some difficulties arose from want of constancy in the batteries, from leakage of electricity, &c., so that many of the experiments were known to be faulty. Twelve experiments, however, against which nothing could be proved at the time of making them, in which the distance of the disks ranged from $\frac{1}{4}$ to $\frac{1}{2}$ an inch, and the power of the battery from 1000 to 2600 cells, gave values of v of which the least was 28.4, and the greatest 29.4 Ohms; and in nine of these the values lay between 28.68 and 28.91. The mean of the 12 was—

$$\begin{aligned} v &= 28.798 \text{ Ohms.} \\ &= 288,000,000 \text{ metres per second.} \\ &= 179,000 \text{ statute miles per second.} \end{aligned}$$

This result is much lower than that of MM. Weber and Kohlrausch, which was $v=310,740,000$ metres per second, but agrees, I believe, more nearly with values recently obtained by Sir W. Thomson, whose method, as well as mine, depends on the B.A. unit. Weber's method depends on the measure of capacity. It is to be hoped that this important physical quantity may soon be determined by methods founded on capacity, and disembarassed from the phenomena of "electric absorption," which occurs in all solid condensers, and which would tend to give too high values of v .

W. J. L. W.

NOTICES AND ABSTRACTS

OF

MISCELLANEOUS COMMUNICATIONS TO THE SECTIONS.